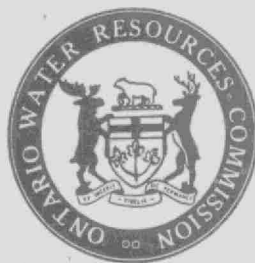


STANDARDS DEVELOPMENT BRANCH OMOE

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## INTERMEDIATE WATER WORKS COURSE



TD  
487  
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1961  
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NOVEMBER 27th to DECEMBER 1st  
1961

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**TD  
487  
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Notes of the intermediate water  
works course : November 27th  
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NOTES

of the

INTERMEDIATE WATER WORKS COURSE

NOVEMBER 27th to DECEMBER 1st, 1961

# WATER WORKS OPERATORS' COURSE

## ONTARIO WATER RESOURCES COMMISSION

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INTERMEDIATE WATER WORKS OPERATORS' COURSE

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WATER WORKS OPERATORS' COURSE  
ONTARIO WATER RESOURCES COMMISSION

November 27, 1961

Intermediate Course

Introductory Statement by Dr. A. E. Berry, General Manager, OWRC

This further course for water works operators, known as the "Intermediate Course", constitutes part of the overall training plan of the Ontario Water Resources Commission.

These lecture notes have been printed for further study and for reference by those who took this series of lectures. They will form part of the reading material recommended in the course.

The present plans call for three courses of training, each being more advanced than the preceding. The "Senior Course", on satisfactory completion, will lead to certification of the operator. It is expected to follow shortly.

The plan of operator training is in keeping with the practice followed in many activities. If we are to be successful in any field of technical practice we must keep abreast of developments and continually strive towards efficiency. In that way there will be satisfaction in work well done and in giving the best public service. Water works operation is a most important part of public service.

WATER WORKS - BASIC MATHEMATICS

by

L. Tobias

Administrative Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

# WATER WORKS - BASIC MATHEMATICS

L. Tobias

Administrative Engineer - OWRC

## INTRODUCTION

The Sages of old tell us that mathematics is a universal language, as it is used in all corners of the world in the same form. This language of mathematics is viewed by many as a very high blown difficult subject to be understood and used by only bearded professors and other such intellectuals.

This idea is quite untrue, as everyone uses mathematics in some form during his everyday life. How many of us have not tried to make something out of wood and had to calculate sizes and measure the pieces, or who has not had to complete an income tax form. We use arithmetic, algebra and geometry for these tasks and these are all part of mathematics.

In the water works field there are certain special problems which require the use of mathematics for their solution and we shall attempt today to blow away the cobwebs around some of these mathematical principles. Some of the ideas we shall discuss today will be quite familiar to many of you, however, they should serve as a refresher course.

## MEASUREMENT

All of the calculation which you make start with some form of measurement and the act of measuring is simply the comparison of an existing condition to a standard condition. For example, we are all familiar with the standard measurement of one foot. This is made for us out of wood or metal or tape and we use this standard to compare it with lengths, widths and heights of objects.

The most important aspect of any measurement is the degree of accuracy used and consequently the accuracy of any calculation is dependant on the accuracy of the measurements. As an example, let us consider the following problem: We have made measurements 116.2, 24.3 and 0.0071, and we want to multiply them all together. By direct multiplication, the product is 20.047986. We must remember however, that the number 0.0071 only has two significant figures, therefore, the accuracy of the calculation is limited to two significant figures. Thus, without any loss of accuracy we can "round off" the other two numbers to three significant figures, and we now multiply  $116 \times 24.3 \times 0.0071$ .

1.  $116 \times 24.3 = 2,818.8$  rounded off to  $\frac{2,820}{20}$
2.  $2,820 \times 0.0071 = 20.022$  rounded off to  $\frac{20}{20}$

It is meaningless to round off the product to 20.05 or 20.048 because we cannot be sure of the absolute accuracy of the measurement 0.0071.

This principle points out the need for care when measurements are taken, so that the correct degree of accuracy is obtained; in other words, don't use a micrometer gauge for one measurement when you use a steel tape in another.

## Units

Once the measurements have been made to the required degree of accuracy, it is necessary to express them all in the same system of units. As an example, if one measurement is made in inches and another in feet, it is necessary to convert both into the same units, either inches or feet, before combining them in a calculation. It may be necessary to convert from one standard of measurement to another so that all factors are expressed in the same system of units.

The system in most common use in Canada is the F.P.S. system, ie. Foot, Pound, Second, in which the units of length, force and time are the "foot", the "pound" and the "second" respectively. In some scientific fields, the C.G.S. system is used, ie. Centimetre, Gram, Second. Using the F.P.S. system, the following expressions are used:

length	foot
force	pound
time	second
area	square foot
volume	cubic foot
velocity	feet per second
acceleration	feet per second per second

Let us now develop a little further the idea of converting from one system to another. The following tables and conversion lists should be found useful:

## Linear Measure

12 inches (in.)	=	1 foot (ft.)
3 feet	=	1 yard (yd.)
$(5\frac{1}{2})$ yards	=	1 rod
$(16\frac{1}{2})$ feet	=	1 mile (mile)
1760 yards	=	1 mile (mile)
5280 feet	=	1 mile (mile)

### Square Measure

144 square inches (sq.in.)	=	1 square foot (sq.ft.)
9 square feet	=	1 square yard (sq.yd.)
30 $\frac{1}{4}$ square yards	=	1 square rod (sq.rod)
160 square rods	=	1 acre
640 acres	=	1 square mile (sq.mile)

### Cubic Measure

1728 cubic inches (cu.in.)	=	1 cubic foot (cu.ft.)
27 cubic feet	=	1 cubic yard

### Liquid Measure

4 gills (gi.)	=	1 pint (pt.)
2 pints	=	1 quart (qt.)
4 quarts	=	1 gallon (gal.)

### Angular Measure

60 seconds (")	=	1 minute (')
60 minutes	=	1 degree (°)
90 degrees	=	1 right angle (L or rt. L)
360 degrees	=	1 circle or revolution (cir. or rev.)

# CONVERSION FACTORS

Acres	x 43,560	= Square feet	Grams	x 15.43	= grains		
				x 0.03527	= ounces		
Acre-feet	x 43,560	= cubic feet	Grams/litre	x 70.1	= grains/ gal.(Imp)		
"	"	x 325,851	= gallons	"	"	x 10.014	= lb/1000 gal.(Imp)
Atmospheres	x 29.92	= Inches of mercury	"	"	x 1000	= parts/ million	
"	x 33.90	= feet of water	Inches	x 2.54	= centimetres		
"	x 76.0	= cms of mercury	Inches mercury	x 1.133	= feet water		
"	x 14.7	= 16/ sq.inch		x 0.4912	= lb/sq.in.		
Cubic feet	x 6.24	= Imp.gals.	Inches water	x 0.07355	= ins.		
"	"	x 1728	= cu.ins.		x 0.03613	= lb/sq.in.	
"	"	x 0.03704	= cu.yds.	Kilograms	x 2.205	= lbs.	
"	"	x 28.32	= litres	Litres	x 0.220	= gals(Imp)	
Cubic feet/sc	x 0.538	= M.G.D.(Imp)		x 61.02	= cu.ins.		
"	"	x 374.4	= gal/min.(Imp)		x 0.03531	= cu.ft.	
Cubic yards	x 27	= cubic feet	Metres	x 3.281	= feet		
	x 168.48	= Imp.gal.		x 39.37	= inches		
(degrees Fahrenheit -32)x5/9	= degrees Centigrade		Miles	x 5280	= feet		
(degrees Centigrade x 9/5)+32	= degrees Fahrenheit		Milligrams/litre	x 1	= parts/ million		
Feet of water	x 0.8826	= Inches mercury	M.G.D.(Imp)	x 1.86	= cu.ft./ sec.		
"	"	x 0.4335	= lb/sq.in.	"	"	x 694	= gal/min. (Imp)
"	"	x 62.4	= lb/sq.ft.	Ounces(fluid)	x 1.805	= cu.ins.	
"	"	x 0.0295	= atmospheres	Parts/Million	x 10	= lbs/million gal.(Imp)	
gallons(Imp)	x 0.1603	= cu.ft.			x 0.0584	= grains/ U.S. gal.	
"	x 277	= cu.ins.			x 0.07016	= Imp.gal.	
gallons(Imp)	x 1.200095	= U.S. gals.					
gallons(U.S.)	x 0.83267	= Imp. gals.					
gal.(Imp)water	x 10	= lbs.water					
gals/min(Imp)	x 0.002673	= cu.ft./sec.					
"	"	x 9.618	= cu.ft./hr.				
"	"	x 1440	= gals/day				
grains/Imp gal.	x 14.285	= parts/million					
grains/Imp gal.	x 142.85	= lb/million gal.					
Pounds	x 16	= ounces					
	x 7000	= grains					
	x 453.59.24	= grams					
Pounds of water	x 0.01602	= cu.ft.					
	x 27.68	= cu.ins.					
	x 0.1439	= gals.(Imp)					
Pounds/sq.ins.	x 2.307	= feet of water					
	x 2.036	= ins. mercury					
	x 0.06804	= atmospheres					

# SANITARY ENGINEERING

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MRS. P.

ASST.  
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MISS. E.

MISS. M.

SUP. WATER WORKS  
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MISS

ASST. SUP.  
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J. M. RIGNEY

J. J. TOTH



## LONG DIVISION

$$\begin{array}{r}
 62.409 \\
 31 \overline{) 1,934,679} \\
 \underline{1 \ 86} \phantom{00} \\
 74 \phantom{00} \downarrow \\
 \underline{62} \phantom{00} \downarrow \\
 126 \phantom{00} \downarrow \\
 \underline{124} \phantom{00} \downarrow \\
 279 \phantom{00} \downarrow \\
 \underline{279} \\
 0
 \end{array}$$

$$\begin{aligned}
 \text{Dividend} &= 1,934,679 \\
 \text{Divisor} &= 31 \\
 \text{Quotient} &= 62,409 \\
 \text{Remainder} &= 0
 \end{aligned}$$

$$\begin{array}{r}
 319 \\
 7423 \overline{) 2,374,196} \\
 \underline{2 \ 226} \phantom{00} \downarrow \\
 147 \ 29 \phantom{00} \downarrow \\
 \underline{74 \ 23} \phantom{00} \downarrow \\
 73 \ 066 \phantom{00} \downarrow \\
 \underline{66 \ 807} \\
 6 \ 259
 \end{array}$$

$$\begin{aligned}
 \text{Dividend} &= 2,374,196 \\
 \text{Divisor} &= 7,423 \\
 \text{Quotient} &= 319 \\
 \text{Remainder} &= 6,259
 \end{aligned}$$

## RATIO AND PROPORTION

One of the most common practices is that of making comparisons. Everyone has compared the prices of cars or boats. When you shop for appliances, you generally make comparisons. The important point is that two numbers are always required to make a comparison, and the numbers may be compared in two ways. For example, if we have two pumps with rated capacities of 450 gal/min and 150 gal/min respectively, then the larger pump is  $450/150$  ie. 3 times as large as the smaller one so that the capacity comparison of the larger pump to the small pump is 3. Similarly, the comparison of the small pump to the large pump is  $1/3$ .

You will notice in the example of the pumps, that the units used were gal/min and the units were the same for both pumps. Thus, the word ratio means a comparison of two numbers of the same kind. For example, the ratio of 20 to 4 may be written  $20/4$  or  $20:4$  or  $20 \div 4$  and the value of this ratio is 5.

A PROPORTION is a statement of equality between two ratios. For example, the ratios  $8:6$  and  $12:9$  have the same value and a proportion can be formed by them such as  $8:6 = 12:9$ . This proportion can also be written  $8/6 = 12/9$  when each ratio is written as a fraction.

In practice numerous problems are encountered in which one ratio is known and we must find an equal ratio of which one of the items is known. As an example, suppose we have a table 6 feet long and 3 feet wide, and we are required to make another one in proportion so that the length is 8 feet. Suppose the width of the second table is  $x$ , then the first ratio is 6:3 and the second is 8: $x$ . The value of the first ratio 6:3 is 2, therefore, the value of the second ratio must also be 2. Hence,  $8/x = 2$  or the width of the second table ( $x$ ) must be 4.

A direct proportion is one in which both couplets are direct ratios. A proportion is understood to be direct unless a problem clearly indicates otherwise. An inverse proportion is one in which one of the couplets is in an inverse ratio. Thus, if 8:4 is inversely as 3: $x$ , one of the ratios must be reversed and the proportion is written  $8:4 = x = 3$  or  $4:8 = 3 = x$ .

In technical literature, one quantity is said to be proportional to another or to vary with it, or increase or decrease with it. These expressions mean that a change in one of the quantities causes, or is accompanied by a corresponding change in the other. To show the significance of direct and inverse proportions, consider the following: Resistance to the flow of water through a pipe is directly proportional to the length of the pipe, ie. the longer the pipe, the greater the resistance.

On the other hand, if a number of men are engaged in laying a watermain, the time required to complete the job is inversely proportional to the number of men working, that is, the more men the less time is required.

In any proportion, the four numbers are given name, eg.  $2:3 = 6:9$ . The 2 and the 9 are called "extremes" and the 3 and the 6 are called "means". It is a property of any proportion that the product of the extremes is equal to the product of the means, ie.  $2 \times 9 = 18$  and  $3 \times 6 = 18$ .

This important principle makes it possible to find an unknown term in a proportion when the other three terms are known. To find an unknown extreme, divide the product of the means by the given extreme and to find an unknown mean, divide the product of the extremes by the given mean.

Example 1. Find the value of  $x$  so that  $81:9 = x:15$

Solution: We write  $81/9 = x/15$

$$\therefore x = \frac{81 \times 15}{9} = 135 \text{ answer}$$

Example 2. Find the value of  $x$  so that  $22.95:45 = 204:x$

Solution: We write  $\frac{22.95}{45} = \frac{204}{x}$

$$\therefore x = \frac{45 \times 204}{22.95} = 400 \text{ answer}$$

Example 3. If a pump discharges 6 gal./min. into a tank and fills it in 20 hours, how long will it take to fill the tank by a pump discharging at 15 gal./min?

Solution: 6 gal./min. fills tank in 20 hours.  
15 gal./min. fills tank in  $x$  hours.

These statements show that we have an inverse proportion, since the bigger pump will take less time. Thus, we reverse one of the ratios.

$$\frac{6}{15} = \frac{x}{20} \quad \therefore x = \frac{20 \times 6}{15} = 8 \text{ hours - answer}$$

Example 4. A pump making 33 strokes per minute discharges 660 gal./min. What is the discharge if the speed is increased to 36 strokes per minute?

Solution: 33 strokes per minute discharging 660 gpm  
36 " " " " "  $x$  gpm

We see by inspection that this is a direct proportion, since an increase in speed means an increase in discharge. So we write:

$$\frac{33}{36} = \frac{660}{x}$$

$$\therefore x = \frac{36 \times 660}{33} = 720 \text{ gpm - answer}$$

## DECIMALS

Just as ordinary numbers, when they become large enough, are expressed in tens, hundreds, thousands, etc., so are we able to express fractions in multiples of ten. A decimal fraction is denoted by a number with a period preceeding it, such as 0.5, 0.25, 0.37. Note that a zero has been used to the left of the point. This simply denoted that the decimal is wholly fractional. Every decimal consists of a decimal point followed by one or more

figures. The decimal point is very important, as the value of the decimal depends on the position of the figures with respect to the point.

If errors are to be avoided, certain points must be remembered in writing decimals. For instance, if you put a zero between the point and the first figure, the whole decimal has been divided by 10. Thus, if 0.5 is changed to 0.05, its value is divided by 10. Since  $0.5 = 5/10$  and  $0.05 = 5/100$ , similarly, if you remove a zero from the left of the decimal, its value becomes increased by 10.

The decimals just mentioned are fractions, but we can have "mixed" decimals which are whole numbers with decimal fractions. For example, 12.5 means  $12\frac{1}{2}$ .

### Addition of Decimals

For addition of decimals and mixed decimals, only one important thing should be remembered. The numbers should be listed one below the other with the decimal points in a vertical line.

Example: A length of watermain is made up by joining the following section: 100 ft., 65.75 ft., 12.125 ft., 3.255 ft., and 0.875 ft. What is the total length of main?

Solution: 
$$\begin{array}{r} 100.0 \\ 65.75 \\ 12.125 \\ 3.255 \\ \underline{0.875} \end{array}$$

181.905      Total length is 181.905 ft.

### Subtraction of Decimals

Subtraction involves only two numbers and as for addition, the decimal points are placed in a vertical line.

Example: What is the difference between 12.7625 and 3.894?

Solution: 
$$\begin{array}{r} 12.7625 \\ \underline{3.8940} \end{array}$$

8.8685 - answer

Note that a zero has been added to the right side of the smaller number to make an equal number of decimal places. This zero, however, has no effect on the value of the decimal.

## Multiplication of Decimals

This is performed in the same way as ordinary multiplication of whole numbers. The numbers to be multiplied are written with the right hand figure of one, below the right hand figure of the other. It is not necessary to have the decimal points lined up and no attention is paid to the point until the multiplication has been done.

Example: Multiply 82.35 by 1.045

Solution:

$$\begin{array}{r} 82.35 \\ 1.045 \\ \hline 41175 \\ 32940 \\ 82350 \\ \hline 8605575 \end{array} \text{ - answer}$$

To find the correct position of the point in the answer, add up the number of decimal places to the right of the point in both numbers, in this case, 5. In the final answer count 5 places from the right hand figure and then position the point.

## Division of Decimals

The procedure for division of decimals is exactly the same as previously explained for whole numbers. The only additional care is required in positioning the decimal point.

Example (1)

$$\begin{array}{r} 2.249 \text{ - answer} \\ 15 \overline{) 123.745} \\ \underline{120} \phantom{00} \\ 37 \phantom{00} \\ \underline{30} \phantom{00} \\ 74 \phantom{00} \\ \underline{60} \phantom{00} \\ 145 \phantom{00} \\ \underline{135} \phantom{00} \\ 10 \text{ - remainder} \end{array}$$

In this case, the divisor 15, has no decimal places, therefore, the position of the point in the answer is directly above the point in the dividend. Long division proceeds as usual.

$$\begin{array}{r} 24.13 \text{ - answer} \\ 2.35 \overline{) 56.7055} \\ \underline{47\phantom{0}} \phantom{0} \downarrow \\ 9\phantom{70} \phantom{0} \downarrow \\ \underline{9\phantom{40}} \phantom{0} \downarrow \\ 305 \phantom{0} \downarrow \\ \underline{235} \phantom{0} \downarrow \\ 705 \phantom{0} \downarrow \\ 705 \end{array}$$

## Rounding Off Decimals

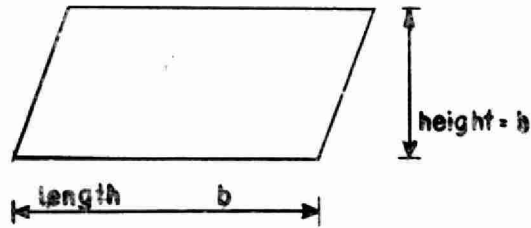
We obtained 174.31649. If we want two places, then we look at the third figure which is 6. Since this is greater than 5, we increase the second figure by one and quote our answer as 174.32. On the other hand, if the third figure was less than 5, we would simply leave the first two figures alone and quote 174.31.

## 1. Area, Volume & Surfaces

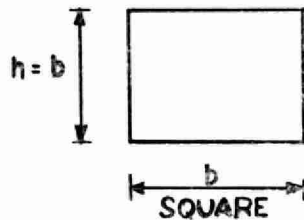
If b and h are in feet,  
then area is in square  
feet.

## Area of Parallelogram

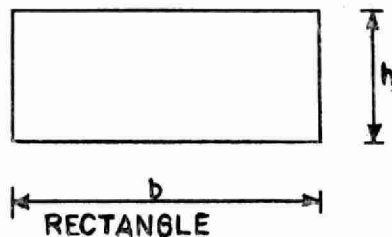
This formula includes squares, rectangles, and rhomboids (4 sides with opposite sides equal).  
 Area of parallelogram = length x height.



$$\text{Area} = b \times h$$

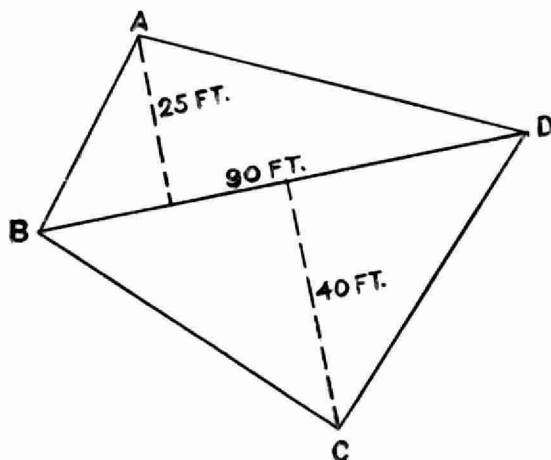


$$\text{Area} = b \times h = b \times b = b^2$$



$$\text{Area} = b \times h$$

## Area of Trapezium (quadrilateral with no sides parallel)



Divide the figure into two triangles by drawing a diagonal.

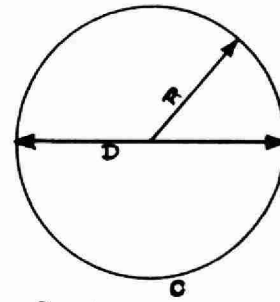
$$\begin{aligned} \text{Area} &= \text{sum of area of two triangles ABD \& BDC} \\ &= \frac{1}{2} \times \text{diagonal} \times (\text{sum of perpendiculars}) \\ &= \frac{1}{2} \times 90 \times 65 = 2925 \text{ square feet.} \end{aligned}$$

## Area of a Circle

D = Diameter

R = Radius

C = Circumference of Circle



$$\text{Area of Circle} = \frac{\pi}{4} D^2 = \pi R^2 \text{ square feet}$$

$\pi$  is the symbol which represents the number of times the radius of a circle will fit around the circumference of the semi-circle.

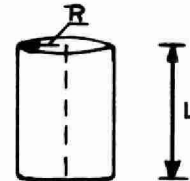
$$\therefore \frac{C}{R} = 2\pi \text{ or } C = 2\pi R = \pi D \text{ since } D = 2R$$

$$\pi = 3.14159 \text{ or approximately } \frac{22}{7} \text{ or } 3 \frac{1}{7}$$

## Cylinder

$$\begin{aligned} \text{Area} &= \text{Circumference of the end} \times \text{length} \\ &= 2\pi R \times L \end{aligned}$$

$$\begin{aligned} \text{Volume} &= \text{Area of end} \times \text{length} \\ &= \pi R^2 \times L \end{aligned}$$



Examples: A microstrainer is 10 ft. diameter and 10 ft. long. What is the total area of the microstrainer fabric?



$$\begin{aligned} \text{Circumference of end} &= \pi \times 10 \\ \text{Surface area} &= \pi \times 10 \times 10 = \\ &314.159 \text{ sq.ft.} \end{aligned}$$

Example: A drum of chlorine is 10 ft. long and 10 ft. in diameter. What is the volume of the chlorine?

$$\begin{aligned} \text{Volume} &= \text{end area} \times \text{length} \\ &= \frac{\pi}{4} \times 10^2 \times 10 \\ &= 0.7854 \times 100 \times 10 \\ &= 785.4 \text{ cu.ft.} \end{aligned}$$

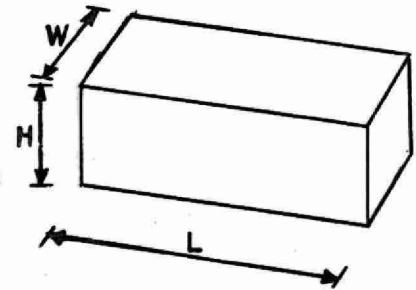


## Rectangular Tanks

$$\text{Surface area of liquid} = W \times L$$

$$\begin{aligned}\text{Area of contact (liquid to tank)} \\ &= \text{area of 4 sides} + \text{area of bottom} \\ &= 2 \times W \times H + 2 \times H \times L + W \times L\end{aligned}$$

$$\text{Volume of tank} = W \times H \times L$$



## Detention Periods in Tanks

The period of detention in a sedimentation tank of the continuous flow type is the time required to fill the tank from empty if there was no outflow. The detention period is, therefore, dependent on the rate of flow and the size of the tank.

Example: A water treatment plant has a circular sedimentation tank 25 ft. in diameter and 15 ft. deep. If the rate of flow through the tank is 3.6 MGD, what is the detention period?

$$\begin{aligned}\text{Step 1. Volume of tank} &= \text{end area} \times \text{height} \\ &= \frac{\pi}{4} \times 25^2 \times 15 \text{ cu.ft.} \\ &= 7360 \text{ cu.ft. (approx.)} \\ \text{Volume of tank in gallons} &= \frac{7360 \times 62.4}{10} \\ &= 46,000 \text{ gallons}\end{aligned}$$

$$\begin{aligned}\text{Step 2. Rate of flow} &= 3.6 \text{ million gal. per day} \\ &= \frac{3,600,000}{24} \text{ gal. per hour} \\ &= 150,000 \text{ gal. per hour}\end{aligned}$$

$$\begin{aligned}\text{Step 3. Detention period} &= \frac{\text{volume of tank}}{\text{rate of flow}} = \frac{46,000}{150,000} = 0.306 \text{ hours} \\ \text{ie. detention period} &= \frac{306}{1000} \times 60 = 18 \text{ minutes (approx.) (18.36)}\end{aligned}$$

## Temperature Conversion

The conversion table gives the formula for changing Fahrenheit temperatures to Centigrade temperatures.

Example 1. What is the Fahrenheit temperature equivalent to 85 degrees Centigrade?

$$\text{Degrees Fahrenheit} = (85 \times 9/5) + 32 = 185^{\circ}\text{F.}$$

Example 2. What is the Centigrade temperature equivalent to 68°F.?

$$\text{Degrees Centigrade} = (68 - 32) \frac{5}{9} = 20^{\circ}\text{C}.$$

### Chemical Dosages

When treating water with hypochlorite solution, the same amount of actual chlorine is required as used in a chlorine solution. It is, therefore, necessary to consider the percentage of chlorine contained in the hypochlorite. The available chlorine is usually marked on the outside of the hypochlorite container.

Example 1: A water plant treats 1.5 MGD with 1.5 p.p.m. chlorine. If a hypochlorite solution is used which contains 70 per cent available chlorine, how many pounds of hypochlorite are required for one day?

Solution: Since the available chlorine in the hypochlorite is 70% one pound of chlorine is contained in 1/0.7 lbs. hypochlorite, ie. in 1.43 lbs. hypochlorite.

Also, a dosage of 1 p.p.m. is equivalent to 10 lbs. chlorine per million gallons of water.

Therefore, the weight of hypochlorite required to treat 1,000,000 gallons of water with 1 p.p.m. chlorine =  $10 \times 1.43 = 14.3$ .

By proportion, the weight of hypochlorite required to treat 1.5 million gal. water with 1.5 p.p.m. chlorine is:

$$14.3 \times \frac{1,500,000}{1,000,000} \times 1.5 = 32.175 \text{ lbs.}$$

Example 2: A water plant operates for 24 hours each day at the rate of 1,600 gal. per minute. If ferrous sulphate is added at the rate of 1.5 grains per gallons, and lime at the rate of 7 grains per gallon, how many pounds of each chemical are used daily?

Solution: Water produced daily =  $1,600 \times 60 \times 24$   
= 2,304,000 gallons  
Amount of ferrous sulphate =  $2,304,000 \times 1.5$   
= 3,456,000 grains.

$$\begin{aligned}\text{Weight of ferrous sulphate used} &= 3,456,000 \div 7,000 \\ &= 493.71 \text{ pounds}\end{aligned}$$

$$\begin{aligned}\text{Amount of lime used} &= 2,304,000 \times 7 \\ &= 16,128,000 \text{ grains}\end{aligned}$$

$$\begin{aligned}\text{Weight of lime used} &= 16,128,000 \div 7,000 \\ &= 2,304 \text{ pounds}\end{aligned}$$

Example 3: Using the information of example 1, and having a stock of hypochlorite on hand of 7,000 pounds, calculate the interval of time that can elapse before it is necessary to reorder hypochlorite, assuming that at least a five-day supply is still on hand at the date of reordering.

Solution: Example 1 has shown that the daily consumption of hypochlorite is 32.175 pounds.

$$\begin{aligned}\text{Therefore, a supply for five days} &= 32.175 \times 5 \\ &= 160.875 \text{ pounds} \\ &\text{say } 161 \text{ pounds}\end{aligned}$$

Hypochlorite available for use before reordering become necessary = 7,000 - 161 = 6839 pounds.

$$\begin{aligned}\text{Number of days that } 6839 \text{ pounds will last is} \\ 6839 \div 32.175 &= 213 \text{ days (approx.)}\end{aligned}$$

For all practical purposes, it is recommended that hypochlorite be ordered in about 7 months time.

BASIC HYDRAULICS FOR OPERATORS

by

J. B. Kirch

Assistant District Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

# BASIC HYDRAULICS FOR OPERATORS

J. B. Kirch

Assistant District Engineer - OWRC

## INTRODUCTION

Hydraulics is the science of fluid flow, and although the general principles involved can apply equally to fluids, gases and vapours, we shall be considering only the most common fluid - water. It is a fact that a great number of operators and others engaged in the water works field look upon hydraulics as a formidable, incomprehensible subject. This is unfortunate for it is certainly not true. The vast majority of everyday water works problems can be solved with a good knowledge of arithmetic and, if a year or two's high school algebra has also been learned, there need be no fears at all about the ability to carry out the necessary calculations. The trouble appears to be not so much in the technical difficulties of calculation as in the understanding and application of the general principles of hydraulics. These principles are basically quite straight forward, and the everyday level of problem can generally be solved by substitution of the known quantities in a formula so that the unknowns can be calculated.

Often we run into problems where there seems to be too many unknown quantities and we don't know how to start. In fact most pipeline and pumping calculations do turn out like this, because we need to determine the size of one or the other before we can get a solution. This does not make the problem any more difficult. The principles still apply, and all we have to do is guess one of the answers and then calculate the other. If we've made a bad guess then we just try again, and with a little bit of experience and care we can get remarkably good at guessing.

Experience is of course an invaluable asset that always pays dividends. The experienced man doesn't really guess at all; he estimates, and generally gets pretty close to the right answer. However, even the most experienced of men will usually welcome, and will certainly benefit from, technical training to accompany his practical "knowhow." The good operator is the one who acquires a workable knowledge of all aspects of his subject, and can adopt a practical attitude towards solving his problems.

It is the intention of this lecture to describe the basic principles of hydraulics and apply them to a few simple practical problems. The lecture will provide the groundwork for further consideration of the subject in the Advanced Course that will be held next year. Hydraulics cover a very wide range and it is only possible to deal with preliminaries at this stage.

Broadly speaking we can say that from the hydraulics point of view two functions are required of a water works system. Firstly, comes the transportation of the water from its source to the consumers, and, secondly, there is the provision of sufficient means of measuring the water so that adequate control can be achieved. Thus, we can consider hydraulics under these two main titles:

- a. Transportation.
- b. Measurement and Control.

Before we can consider these two matters in detail however, it is necessary to deal first with a few general principles.

#### SOME FACTS ABOUT WATER

1 cubic ft. weighs	62.4 lbs.
1 gallon weighs	10 lbs.
1 U.S. gallon weighs	8.33 lbs.
1 Imp. gallon	= 1.2 U.S. Gallons
2.31 ft. of water	= 1 lb. per sq.in. (pressure)
1 Million gals./day (MGD)	= 694 G.P.M.
1 MGD	= 1.86 cu.ft. per second (cfs)
1 MGD (U.S.)	= 1.55 c.f.s.
1 c.f.s.	= 373 G.P.M.

#### GENERAL PRINCIPLES

Under the heading of general principles we shall consider the basic factors that are used in hydraulic calculations. These include:

- a. Pressure and Head
- b. Velocity and Discharge
- c. Energy and Horsepower

##### a. Pressure and Head

Any "body" at rest exerts a pressure on all surfaces with which it is in contact. The magnitude of this pressure depends on the density and volume of the material of which the 'body' is composed. Also, since the body is at rest the forces or pressures are in balance, and this means that a similar pressure is exerted in the opposite direction by the surfaces with which it is in contact.

The air exerts a pressure on the earth's surface which amounts to about 14.7 lbs./sq.in. This is what we call atmospheric pressure. In the same way a column of water (Fig. 1), exerts a pressure on its base surface amounting to the volume multiplied by the density.

i.e:  $P = wV$

The density of water is about 62.4 lbs./cu.ft. Therefore the pressure  $P = 62.4 \times \text{Volume}$ . However, we are more usually concerned with the intensity of pressure;

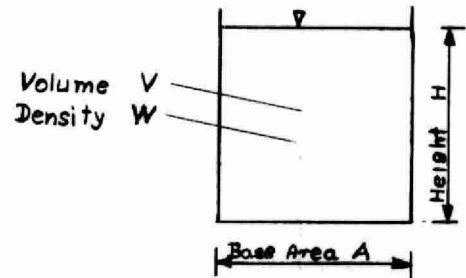


Fig. 1

i.e: the pounds per sq. ft. or usually pounds per sq. in. (p.s.i.).

Thus the Total Pressure is  $P$  lbs., and the Intensity of Pressure  $= P/A$  (where  $A$  is equal to area of the base surface)

But since the volume  $= A \times H$

The intensity of pressure  $= \frac{62.4 \times A \times H}{A} = 62.4 \times H$  p.s.f.

Note: 62.4 is the density in lbs. per cu. ft. and  $H$  is usually measured in feet. Therefore  $62.4H$  gives us the pressure in lbs. per sq. ft. If we want it in sq. ins. we must divide by 144 which is the area of one ft. square in sq. inches.

Ex. Q. What is the total pressure and the pressure intensity at the base of a standpipe 80 ft. high and 15 ft. in diameter?

A. Pressure Intensity  $= 62.4 \times 80 = 4,992$  lbs. per sq. ft.  
(or about  $2\frac{1}{2}$  tons).

$$= 4,992 / 144 = 35 \text{ p.s.i.}$$

$$\text{Total Pressure } 4,992 \times \frac{\pi \times 15^2}{4} = 883,000 \text{ lbs.}$$

This is of course the weight of water in the standpipe, and since a gallon of water weighs 10 lbs. The volume of water in the tower  $= 88,300$  gallons.

Head, is a term we use all the time in water works practice. If we have a pumping problem then we need to know the head against which the pump will have to drive the water. If its a supply problem on the other hand, the head provides the driving force that is required to overcome friction and other

losses in the conduits and supply the water at a suitable pressure to the consumer. Of course pressure and head are really the same thing, and are closely allied with energy which we shall consider later.

### b. Velocity and Discharge

Discharge is the term used to describe the quantity of water flowing in a conduit. It is the volume of water passing a given location in a specified time. Hence we refer to discharges in gallons per minute (GPM) or cubic feet per second (CFS). Velocity is the rate at which the water is moving. Discharge and velocity are related by the formula:  $Q = V \times A$  where A is the area of cross-section at the location the velocity is V.

Ex. Q. What is the discharge from a 6" pipe flowing full at 2 f.p.s?

$$A. Q = V \times A = 2 \times \frac{\pi \times (\frac{1}{2})^2}{4} = 0.393 \text{ c.f.s.} \times 373 = 147 \text{ G.P.M.}$$

Note that we must be very careful to get the units right.

If the velocity is in ft. per second we must calculate the area in sq. ft. to get the discharge in c.f.s. A useful conversion factor to remember is 1 c.f.s. is approximately equal to 373 G.P.M.

As another example we might wish to estimate the flow in a creek so that we could determine whether it was suitable for use as an emergency supply for fire fighting or other purposes.

The depth and area can be estimated. Say 3' average depth x 10' wide. Then the velocity can be measured by timing a floating object. Say it travels 50 ft. in 1 minute and 40 seconds. The velocity then is equal to  $\frac{50}{60 + 40} = \frac{1}{2}$  f.p.s.

Area equals  $10 \times 3 = 30$  sq. ft.

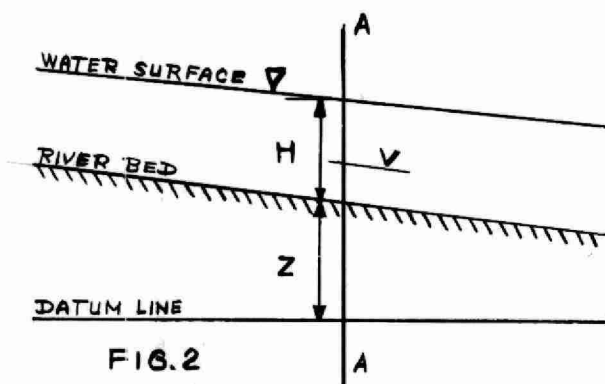
$$Q = 30 \times \frac{1}{2} = 15 \text{ c.f.s.} \\ = 15 \times 373 = 5,600 \text{ G.P.M.}$$

### c. Energy

The term energy is widely used in hydraulics because it is the basic factor that embraces the other characteristics. If we want to move water we have to perform work on it and to perform work we have to expend energy. If the water has energy of its own it can expend some of it in moving - i.e. under gravity. Energy is a combination of pressure, elevation and velocity.



Let us take a simple example to explain this:



We wish to calculate the energy of a water at section A-A of a river.

Total Energy = Pressure Energy + Velocity Energy + Elevation Energy.

Energy must be calculated above a datum line for reference purposes because obviously the elevation must be measured from somewhere.

In Figure 2 the elevation head = Z ft. above datum.

The pressure head is due to the depth of water = P (p.s.i.). However, we need this also in feet, and as we have already noted  $P = wH$ . Therefore, the pressure head in feet units =  $H = P/w$ . Note that the pressure head in this case is just the depth of water because actually we are dealing in total energy per unit of area.

The velocity head is the kinetic energy that the water has due to its velocity. This is expressed as  $\frac{V^2}{2g}$ , where V is the velocity and g is a constant for any location usually called the acceleration due to gravity. Thus to combine these we have:

Total Energy =  $Z + \frac{P}{w} + \frac{V^2}{2g}$ . This formula is known as Bernoulli's theorem, and is probably the most important one used in hydraulics. The total energy concept is basic to the solution of any hydraulic problem involving fluids in motion. In the above formula both Z and H ( $= P/w$ ) refer to the position of the water relative to the datum, whereas  $\frac{V^2}{2g}$  refers to the velocity of motion of the water.

This then gives us two types of energy.

The Potential energy of a body is that energy stored in it by virtue of its weight and elevation above a certain datum line.

Potential Energy (P.E.) =  $W \times H$  ft. lbs. (W is the weight of the water).

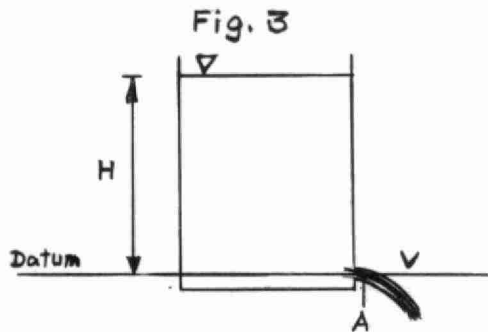
The Kinetic Energy of a body is that energy stored in it by virtue of its weight and velocity.

$$\text{Kinetic Energy (K.E.)} = W \times \frac{V^2}{2g}$$

If we now accept the Principle of the Conservation of Energy we can say that the total energy does not change with time as the liquid moves, and, therefore, the gain in kinetic energy is equal to the loss of potential energy.

$$\text{i.e. } W \times H = W \times \frac{V^2}{2g} \text{ or } H = \frac{V^2}{2g}$$

Let us take a simple example to explain this:



We want to know what would be the velocity of water coming from a small hole at the bottom of a tank containing 10 feet of water (Fig. 3).

First we must select a datum line and, for convenience here, we shall use the horizontal line through the centre of the opening because then the elevation energy ( $Z$ ) is zero.

In the tank the pressure energy is  $H$ , and since the water is not moving, the velocity  $V$  is zero.

$$\text{Total Energy} = 0 + H + 0 = H \text{ (feet)}$$

At point A the pressure energy is zero (above atmospheric pressure) and the velocity energy is  $\frac{V^2}{2g}$

$$\text{Total Energy} = 0 + 0 + \frac{V^2}{2g} \text{ (feet)}$$

But since these two are equal, we can see that  $H = \frac{V^2}{2g}$  or  $V = \sqrt{2gH}$ .

In our example  $H = 10$  ft.  $V = \sqrt{2g \times 10} = \sqrt{2 \times 32 \times 10} = \sqrt{640}$   
 = approximately 25.3 f.p.s.

The value of  $g$  (the acceleration due to gravity) varies very slightly from place to place on the earth. It is actually a measure of the rate of change of velocity of a free-falling object falling towards the earth. It varies with the height of the land above sea level; the nature of the rock and soil deposits in the area, and the true speed of rotation of the earth. For all practical purposes a value of 32 ft. per second per second can be used.

Actually, in the above example, the true velocity will not be as high as 25.3 f.p.s. because all of the potential energy is not converted into kinetic energy. There will be losses of

energy due to the abruptness of the change of section, and also due to friction around the sides of the opening. If the orifice has sharp edges and is not tapered, the true velocity will be about 62% of the theoretical one.

$$\text{That is the true velocity} = \frac{62}{100} \times 25.3 = 15.7 \text{ f.p.s.}$$

For accuracy therefore we usually write the formula as  $V = C\sqrt{2gH}$ , and we call C the coefficient of discharge. It is determined by experiment for any particular type of orifice, and varies from about 0.62 for a small sharp-edged orifice to as high as 0.98 for a mouthpiece that conforms to the shape of the jet.

### Horsepower

Horsepower is the practical way to measure or describe energy. It indicates either the amount of energy that has to be expended or the ability of a machine to do a certain amount of work in a specified time.

As we have noted already, energy is measured in ft.-lbs. and 1 horsepower is equivalent to 33,000 ft. lbs. per minute. Say we want to find what horsepower motor to use to drive a 100 G.P.M. pump when the total head is 200 ft.

$$\text{Energy required} = 100 \times 10 \times 200 = 200,000 \text{ ft.lbs./min.}$$

$$\text{Horsepower required} = \frac{200,000}{33,000} = 6 \text{ HP}$$

Since we don't want to overload the motor, and the pump-motor combination may be only about 60 to 70% efficient, we would use a 10 HP motor.

### TRANSPORTATION OF WATER

Water is often conveyed from one location to another by a pipeline. The determination of how big a pipe is required resolves itself into a calculation of how much energy is lost in friction and other causes, so that the energy lost can be compared with the energy available. We have already discussed how to compute the energy that is available, so that under this section we are left with how to calculate the energy losses.

### Friction Loss

Friction losses in a long pipeline are by far the greatest numerically. A tremendous amount of experimental research has gone into the study of friction losses in pipes

because it is a subject that cannot be solved entirely theoretically. Three things are important to remember in the consideration of friction losses. They are:

1. Friction losses are approximately proportional to the square of the velocity.
2. Friction losses are proportional to the surface area of contact between the water and the conduit.
3. Friction losses depend on the nature of the conduit.

To explain this in more detail, let us consider the original formula that was presented by Chezy based on these three experimental findings. The Chezy formula is:

$$V = C\sqrt{mi}$$

V is the velocity of flow in the pipe.

C is an experimentally found coefficient.

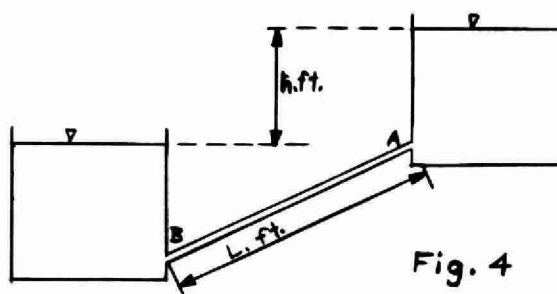
m is the hydraulic radius or hydraulic mean depth.

i is the hydraulic gradient.

Writing the formula another way, we have  $V^2 = C^2 \times m i$

$$\text{or gradient } i = \frac{V^2}{C^2 \times m}$$

and the easiest way to explain this is to consider the flow in a pipeline connecting two reservoirs. The length of the pipeline is L ft. The difference in elevation between the two water levels is h ft. The hydraulic gradient then is merely  $h/L$  and is usually expressed as the loss of head in feet per thousand feet. The hydraulic radius is defined as the area of flow divided by the wetted perimeter. For a pipe this is equivalent to the cross-sectional area divided by the circumference and is equal to one-quarter of the diameter (when flowing full).



Ex. If the head loss is 10 ft. per 1000', how much water would flow between the reservoirs in a pipe of 3" diameter (C = 100).

$$i = h/L = 10/1000 = 1/100 = 0.01, m = d/4 = \frac{1}{4}/4 = 1/16$$

$$V = 100 \times \sqrt{1/100 \times 1/16} = 100 \times 1/10 \times \frac{1}{4} = 100/40 = 2.5 \text{ ft./sec.}$$

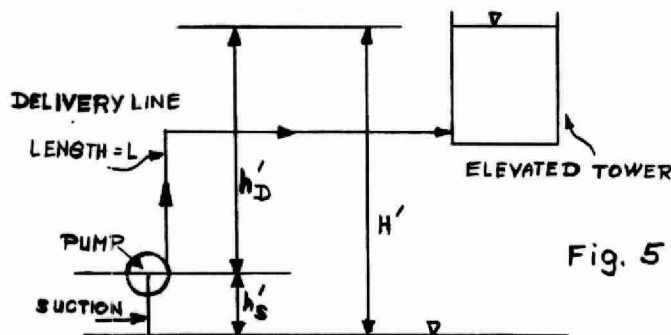
$$Q = V \times A = 2.5 \times \frac{\pi \times \frac{1}{4}^2}{4} = 2.5 \times \frac{\pi}{64} = 0.031 \text{ c.f.s.} \times 373 = 11.5 \text{ G.P.M.}$$

Actually this sort of calculation is quite tedious and lengthy if one has to do a lot of them and can become even more time consuming when the more advanced formulae, which are based on extensive experimental evidence, are used. Consequently, it is convenient to be able to read the required information off a chart or nomogram as they are often called. At the back of this paper is a nomogram of the Hazen-Williams Formula for flow in pipes. This is probably the most commonly used and is suitable for all normal piping problems.

Dotted lines have been drawn on the nomogram to indicate how to use it. The example shown covers the case of a 24" pipe with a Hazen-Williams coefficient of 100 set at a gradient of 3.8 ft. per 1000 ft. From the chart the velocity can be read as 4.2 f.p.s. and the discharge as 5000 IGPM (6000 USGPM).

### Pumping Head

Before we finish with this section let us calculate a small pumping problem using this chart, since this is one of the most important in the transportation of water. Fig. 5 indicates the details of a pumping set-up where we want to know what size pipe to put in.



By taking elevations we can determine the head of the elevated tower water level above the water level of the source =  $H$  ft.

Fig. 5

Note that the delivery head  $h_D$  can be as great as we like, but the suction head  $h_s$  is quite critical. It is desirable if at possible to eliminate  $h_s$  by putting the pump in a separate well below the water level or else using a turbine pump. If this is not practical, however,  $h_s$  should be kept as small as possible and never greater than 15 to 20 feet. Large suction heads tend to cause pitting and erosion of the impeller blades due to cavitation.

Ex. Say we want to pump 200 USGPM and we find a pump rated at this discharge against a head of 150 ft. and the water level in the tank is 134 ft. above the water level from which we are pumping. The length of the pipeline is 500 ft.

Then available head =  $150 - 134 = 16$  ft.

This means that 16 feet of head can be used up in friction and other losses. There are ways of calculating the other losses, but it is usually quite accurate enough to allow between 5 and 10% and leave 90 to 95% for friction. Generally speaking, the longer the pipeline the less effect the other losses have on the result. For distribution systems and long supply lines it is not uncommon to ignore all but the friction losses, or else add only 1 or 2% for other energy losses.

Here we can say that we can expend the energy equivalent to 15 ft. of water in friction loss.

Friction Loss = 15 ft. in 500 ft. of pipeline  
which is a rate of 30 ft. per  
1000 ft.

Using the chart we find we need a pipe diameter of just under 4" and since 4" is the next higher standard size this is what we would use.

#### Channel Flow

Water can also be conveniently carried in channels when not under pressure. The principles of hydraulic gradient and hydraulic mean depth apply to channel flow in exactly the same way as we have indicated in pipes. There are, however, rather more exceptions to the simple rules and channel flow can conveniently be left to the advanced course.

#### MEASUREMENT AND CONTROL

Measurement and control of water is, of course, an extremely far reaching subject, and it would take many lectures to cover all aspects of it. Most water works have one or more water meters for recording the amount of water that is being pumped, and this constitutes the first step in measurement. Always bear in mind that you cannot successfully control any system unless you provide a method of measuring the variables. In many control devices the measurements are not actually recorded at each stage of the operation, but the components are there to do so if it were so desired.

In order to measure flow of water, or pressure and velocity - or for that matter anything, you have to create a change in the conditions and then measure the effect of that change. To estimate the flow in a channel or watercourse we put in a weir so that we can measure the head over it, or a meter, so that we can calculate the velocity from the speed of rotation of the propeller. In pipes, we can use an orifice that converts pressure energy into velocity energy (because the velocity must increase through the smaller opening) and so measure the change in pressure energy or head.



There are a great many variations on all of these methods, but probably the most common of all is the Venturi Meter (or Dall Tube). This is a specially designed contraction in a pipeline that causes a conversion of pressure energy into velocity energy and back to pressure energy. It results in a minimum of energy loss and is therefore extremely useful for measurement and control of flow. Most water works plants have a Venturi Tube in their system for it is the same principle as the injector that provides the vacuum in a chlorinator.

Figure 6 shows the configuration of a simple Venturi meter. The velocity and diameter in the pipe are respectively  $V_1$  and  $d_1$  and in the throat are  $V_2$  and  $d_2$ . By connecting piezometer tubes to the main pipe and the throat the loss of head energy can be measured as the difference between the two water levels. This is equal to  $h$  ft. The velocity energy acquired as a result of the loss of head energy is converted back into head energy in the diverging section of the meter beyond the throat.

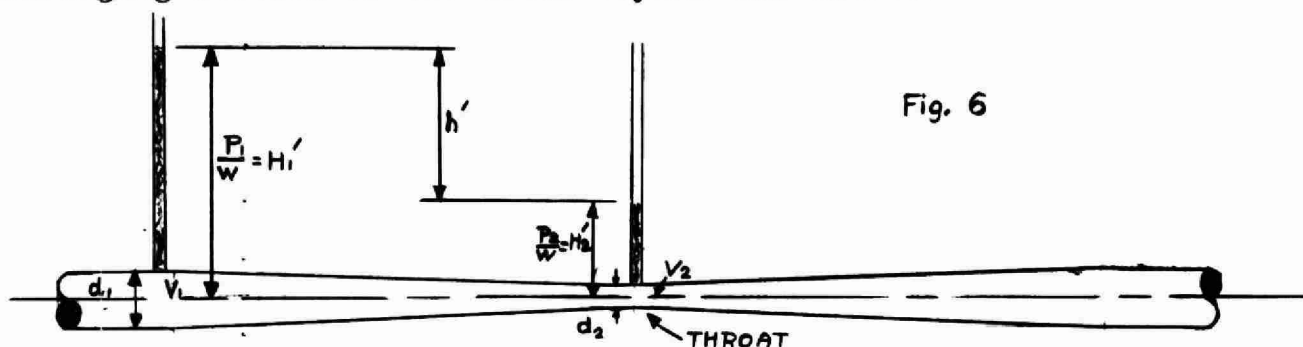


Fig. 6

We can now apply our energy principles to the two sections where we measure the head. By using the centreline of the pipe as a datum line the position head ( $Z$ ) is zero unless, of course, the Venturi Meter is not installed in a horizontal position.

$$\text{In the upstream pipe the total energy} = \frac{P_1}{w} + \frac{V_1^2}{2g}$$

$$\text{At the throat the total energy} = \frac{P_2}{w} + \frac{V_2^2}{2g}$$

$$\text{If there is no energy loss these are equal.} \therefore \frac{P_1}{w} + \frac{V_1^2}{2g} = \frac{P_2}{w} + \frac{V_2^2}{2g}$$

$$\text{or } \frac{P_1}{w} - \frac{P_2}{w} = \frac{(V_2^2 - V_1^2)}{2g} \text{ and since } \frac{P_1 - P_2}{w} = h, h = \frac{V_2^2 - V_1^2}{2g}$$

But the quantity of water flowing in the pipe is constant since none is being taken away between the upstream pipe and the throat.

Quantity of water = AV  $\therefore A_1 V_1 = A_2 V_2$  and  $A_1 = \frac{\pi d_1^2}{4}$  &  $A_2 = \frac{d_2^2}{4}$

Having gone this far it is convenient to consider an actual case:

Ex. If  $d_1 = 6"$  and  $d_2 = 3'$  and we measure the difference  $h$  as  $6"$ , what is the quantity of water flowing in the pipe?

$$A_1 = \frac{\pi}{4} \times \left(\frac{1}{2}\right)^2 = 0.196 \text{ sq. ft.}$$

$$A_2 = \frac{\pi}{4} \times \left(\frac{1}{4}\right)^2 = 0.049 \text{ sq. ft.}$$

$$\therefore 0.196 V_1 = 0.049 V_2$$

$$\text{or } V_2 = \frac{0.196}{0.049} V_1 = 4V_1$$

We also know that  $V_2^2 - V_1^2 = 2g \times h = 2g \times \frac{1}{2} = g = 32$

If we now put  $V_2 = 4 \times V_1$  in this formula we have:

$$(4 \times V_1)^2 - V_1^2 = 32 \quad \text{i.e. } 16V_1^2 - V_1^2 = 32$$

$$15V_1^2 = 32$$

$$\& V_1^2 = \frac{32}{15} = 2.13$$

$$\& V_1 = \sqrt{2.13} = 1.46 \text{ f.p.s.}$$

$$\therefore Q = A_1 V_1 = 0.196 \times 1.46 = 0.286 \text{ c.f.s.} \times 373 = 106 \text{ G.P.M.}$$

Actually, as we noted before, there is a slight loss of head due to friction and turbulence, and therefore the true difference in head between the pipe and the throat would be a little smaller than that which is measured.

As before, we have to use a coefficient to allow for this, which has to be determined experimentally. A good average value of the coefficient would be 0.97 so that the true discharge would be

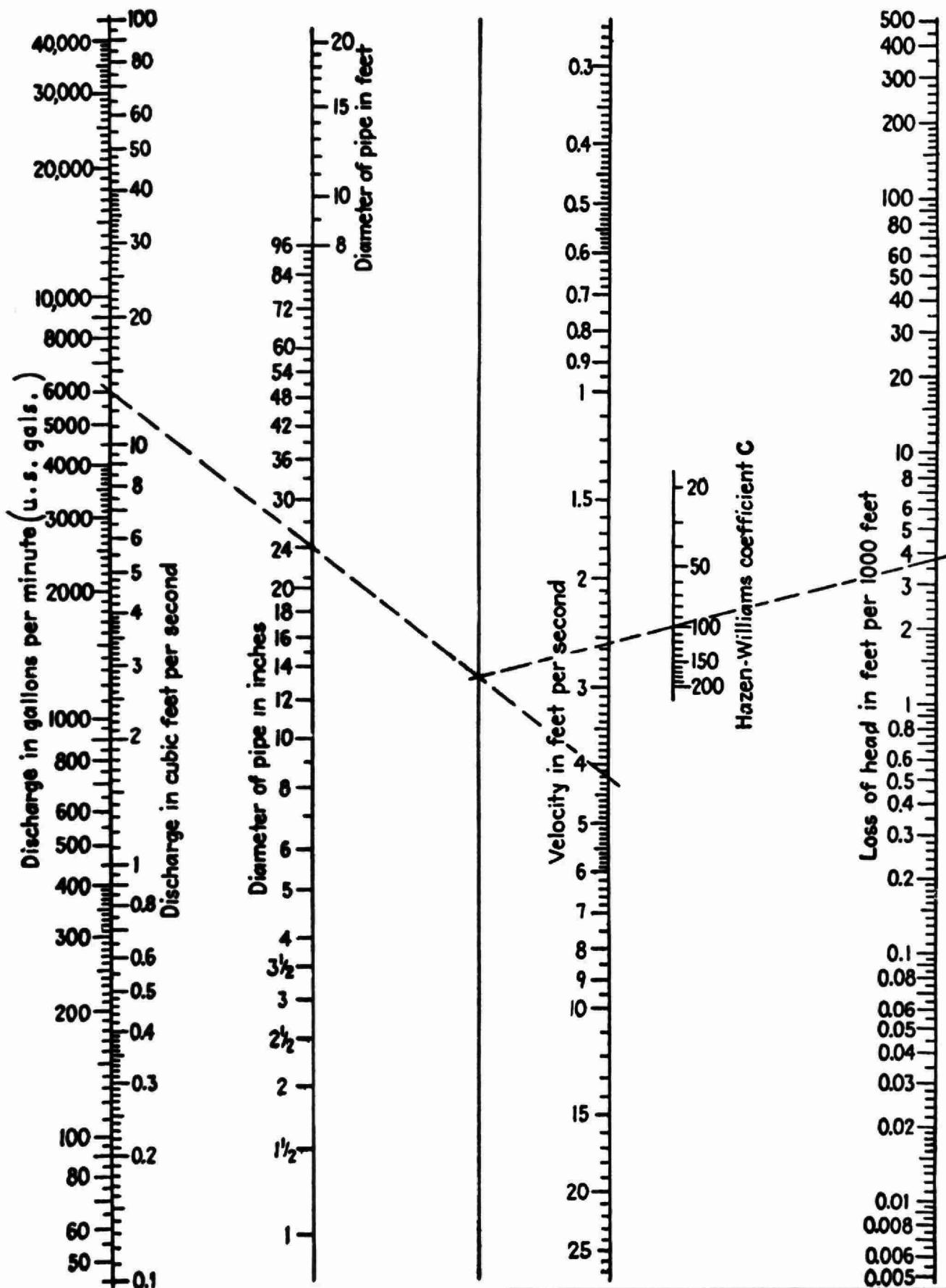
$$0.97 \times 106 = 103 \text{ G.P.M.}$$



In practice a flow of 103 GPM in a 6" pipe is quite low, and a Venturi tube that was suitable for all flows would have to be able to measure head differences of from a few inches to several feet. If we were to use straight piezometer tubes for this purpose it would be most inconvenient, so that it is usual to connect the tubes to either end of a mercury manometer or U-tube. Then, since mercury is 13.6 times as heavy as water, we can measure a few inches difference in the mercury level and convert it into head difference of water by multiplying by 13.6.

i.e. if the head difference was 3" mercury, the true water head difference would be  $\frac{3}{12} \times 13.6 \times 0.97 = 3.3$  ft.

In the case of the chlorinator injector, the quantity of water and ratio of diameters of pipe and throat are adjusted so that all the head energy is converted into velocity energy. A vacuum is thus produced at the throat. This absence of pressure then allows the metered amount of chlorine to enter the pipe at this location and become mixed with the water. The injector has to be carefully constructed of special materials that will withstand the corrosive and erosive conditions produced.



ONTARIO WATER RESOURCES COMMISSION

Alignment Chart for Flow  
in Pipes.

Hazen-Williams Formula - *Amos* 5.24  
Chart No.

THE CONSTRUCTION AND MAINTENANCE OF DEEP WELLS

by

D. N. Jeffs

Acting Supervisor - Ground Water Branch - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

# THE CONSTRUCTION AND MAINTENANCE OF DEEP WELLS

D. N. Jeffs

Acting Supervisor - Ground Water Branch - OWRC

## INTRODUCTION

A summary in the Canadian Municipal Utilities Magazine of February, 1961 indicates that there are 205 municipal water works systems dependant on ground water for their source of supply. The number of systems dependant on surface sources is 245. In 1958 approximately 670,000 people were provided with ground water by municipal water works systems in Ontario.

## REVIEW OF GROUND WATER TERMS AND CONDITIONS

Before discussing the construction and maintenance of deep wells it is desirable to review several of the basic terms and conditions concerning ground water.

Ground water is present near the earth's surface in the pore spaces between the grains of unconsolidated overburden deposits and in fractures and pore spaces in consolidated bedrock materials. The term ground water is applied to the water in the saturated portions of the overburden and bedrock materials.

Ground water moves under the influence of gravity from places of higher elevation to places of lower elevation. The movement of ground water through pores and fractures is hindered by friction. The resistance to movement is greater through small pores and fractures and lesser through large pores and fractures.

The level at which ground water rests in a well when no water is being discharged from the well is termed the static level. The static level is described commonly as the distance from the top of the well to the surface of the water. Similarly the pumping level is the level at which water rests in a well at any given time when the well is being pumped, and is measured commonly as the distance from the top of the well to the surface of the water.

The water in a well will be under either water-table or artesian conditions.

The distinguishing feature of water-table conditions is that the water in the well does not rise above the level at which it is encountered when the well is being constructed except for normal seasonal variations in the level of the water table.

The distinguishing feature of artesian conditions is that the water in the well rises above the level at which it was encountered when the well is being constructed.

Artesian conditions are created by the confinement of water in a water-bearing formation by an overlying layer of fine grained material through which water will pass only at a very slow rate. The pressure which causes the water to rise is simply the weight of the water from higher portions of the water-bearing formation less the loss in pressure due to the friction created by water moving through pores and fractures. In general water which falls on an area of high elevation and moves to areas of lower elevation through a water-bearing formation beneath a fine grained confining layer will be under artesian conditions. Artesian wells flow when the top of the well casing is below the static level of the well.

## WELL CONSTRUCTION

### Test Drilling

The type of well to be constructed will depend on the geological and ground-water conditions in the area. The size of the well and the well components will depend both on the amount of water that the well will be required to produce and the geological and ground-water conditions.

In nearly all areas it is necessary to drill one or more test holes or test wells before the construction of a municipal well can be completed. The test holes or wells provide information on the geological and ground-water conditions and through the use of pumping tests permit calculations to be made of the quantity of water available at any given site. An equally important function of pumping tests is to determine the chemical quality of the water.

On Commission test-drilling projects test holes or test wells which are designed to end in bedrock are drilled generally with a sufficiently large diameter to accommodate the final pumping equipment and if a suitable supply of water is found the test hole becomes the finished well. This practice is followed since the fractures yielding water in rock wells are very irregular and a larger diameter well has more chances of intersecting such fractures than a well of smaller diameter.

After the test-drilling programme has been completed the site or sites for the construction of municipal wells and the type of construction can be selected. The basic condition governing the type of well will be whether the well will end in unconsolidated deposits of sand and gravel or in consolidated bedrock formations.

### Wells Ending in Sand and Gravel Deposits

Many of the large capacity municipal wells in the province obtain water from sand and gravel deposits. The main problem involved in the construction of a well in sand and gravel is to prevent the entry of fine grained particles of silt and sand into the well. This is accomplished by using a

well screen to hold out the coarser materials and developing the well thoroughly during construction to remove the fine particles from the sand and gravel formations near the well. Well screens should be selected according to the character of the water-bearing formation and the size of the materials introduced in any gravel pack. Current design practice uses a screen that permits 40 to 70 per cent of the sands and gravels around the well to be drawn through the screen and removed.

Many kinds of metals are used in well screens. The alloys generally have a greater tensile strength and resistance to corrosion than the unalloyed metals. Table I lists many of the metals used in well screens together with a summary of the tensile strength and the resistance to corrosion by water and acid treatment.

The two main types of wells used for sand and gravel formations are naturally developed sand and gravel wells and gravel-packed wells. Other names for gravel-packed wells are gravel-filter or gravel-wall wells.

Table 1 Properties of Metals Used in Well Screens

Name of Metal	Analysis	Tensile Strength psi		Resistance to	
		Yield	Ultimate	Corrosion by water	Acid Treatment
Everdur	Copper 96% Silicon 3% Manganese 1%	90,000	115,000	Very Good	Very Good
Stainless Steel	Steel 74% Chromium 18% Nickel 8%	90,000	110,000	Very Good	Good
Monel	Nickel 70% Copper 30%	75,000	100,000	Excellent	Very Good
Silicon Red Brass	Copper 83% Zinc 16% Silicon 1%	72,000	83,000	Good	Good
Super Nickel	Copper 70% Nickel 30%	67,000	69,000	Excellent	Very Good
Armco Iron	Iron 99.84%	50,000	55,000	Fair	Poor
Steel	Manganese .20% Carbon .08/.15	45,000	50,000	Poor	Poor

## Naturally Developed Sand and Gravel Wells

The main components of naturally developed sand and gravel wells are a protective casing which extends from above the surface of the ground to or into the water-bearing formation and a well screen which is set opposite the water-bearing formation. If the water-bearing formation is thick and contains layers of fine grained sediments sections of well screen may be set opposite the coarser materials and blank sections of pipe set opposite the finer materials. The screen may be attached directly to the bottom of an inner working casing or sealed to the protective casing by means of a lead packer or other commercially manufactured seal. The bottom of the screen should be closed with a plug of cement or the material of which the screen is made.

Naturally developed sand and gravel wells are suitable for coarser grained materials and deposits which contain materials with a range of grain size.

## Gravel-Packed Wells

The main components of gravel-packed wells are an outer protective casing, an inner working casing, a well screen set opposite the water-bearing formation and a gravel pack of clean washed gravel introduced around the outside of the well screen.

The protective casing extends from above the surface of the ground to or into the water-bearing formation.

The working casing is attached to the top of the well screen by a welded joint or a threaded coupling and extends upwards either to a point above the surface of the ground or to a point well above the bottom of the protective casing. In order to reduce corrosion the bottom portion of the working casing may be of the same metal as that in the well screen.

As is the case in a naturally developed sand and gravel well, if the water-bearing formation is thick, blank sections of pipe may be set opposite the finer grained portions of the aquifer. The screen is attached directly to the bottom of the working casing and the bottom of the screen is sealed with a plug of cement or the metal of which the screen is made.

The gravel in the gravel pack should be composed of well rounded particles which have been washed and sized. The size of the gravel should be selected carefully with reference to the character of the water-bearing formation opposite the screen to ensure a sand-free water supply. Silica gravel has the best resistance to corrosion and is the material most commonly used in gravel-packed wells.

Gravel-packed wells are used for coarser grained materials, deposits which contain materials with a range of



grain size and in addition permit the development of water from the finer-grained gravels and sands which have little variation in grain size.

### Rock Wells

Rock wells are dependable sources of supply for many municipal waterworks systems. The main problem in constructing a rock well is to provide a good seal between the protective casing and the rock to prevent the entry into the well of clay, silt and other fine particles from the overburden formations above the bedrock. This problem is more difficult when the materials directly on top of the bedrock are water-bearing silts, sands and gravels.

Most rock wells consist of a single protective casing extending from above surface to or into the top of the water-bearing formation.

The main methods used to seal the casing to the bedrock are by driving casing equipped with a drive shoe into the bedrock surface or by grouting an annular space between the casing and the rock in the upper portion of the bedrock formations. If these methods do not prevent the entry of overburden materials it may be possible to install a liner inside the protective casing which will extend below the bottom of the protective casing and be sealed to the rock portion of the well by a lead or other commercially manufactured packer. Cement grout may be introduced in the annular space between the liner and the bedrock.

### Flowing Wells

Great care must be exercised in constructing wells which end in artesian formations that possess sufficient pressure to flow above the surface of the ground. In the construction of such wells the initial drilling operations should extend into, but not through, the impermeable formation confining the water under artesian head. The protective casing and grout in the annular space surrounding the protective casing should be installed and ample time should be allowed for the grout to set before drilling proceeds into the artesian formation. The drilling operations into the artesian formation are continued in a normal manner.

### Water Quality

The water from many wells obtaining water from sand and gravel deposits has an iron content in excess of the recommended maximum of 0.3 ppm. This is the most common quality problem encountered in sand and gravel aquifers. Such water requires iron-removal treatment to ensure satisfied customers.



Rock wells present a greater variety of quality problems which should be determined during the pumping tests. Care should be exercised to be sure that the water does not have a chloride content in excess of 250 ppm. The water from rock wells in Ontario generally is very hard and in nearly all cases no treatment is provided for the hardness. Quality problems which may require treatment are high contents of hydrogen sulphide or iron or a combination of these. Coliform bacteria may move considerable distances through bedrock formations from locations where the bedrock is close to surface to the sites of municipal wells thereby requiring chlorination treatment for the well water.

The advantages common to most well supplies are constant low temperature, freedom from turbidity and colour problems and general freedom from taste and odour problems.

Wells should be provided with a sanitary seal of cement grout or concrete extending from the land surface to a sufficient depth to prevent the seepage of surface water or other contaminating materials down the outside of the casing into the water-bearing formation.

## MAINTENANCE OF WATER WELLS

### Water Level Records

Accurate records of static and pumping levels in water wells are essential aids for determining if and when maintenance is required. If the static level of a well remains essentially the same, but the pumping level shows a steady decline it can be deduced that the openings through which water enters the well are being plugged and the well should have suitable maintenance. On the other hand if both the static level and the pumping level in a well show a steady decline it can be deduced that the well is withdrawing more water than the amount entering the area of influence. If this trend continues it may require re-setting the pump at a lower level or constructing other wells suitably spaced to provide additional water without interfering seriously with the existing well.

### Deposits in Wells

Ground water may carry sizable quantities of bi-carbonates, sulfates, and chlorides of calcium, magnesium and sodium in solution. Often present although in smaller quantities are compounds of iron, manganese, silica, nitrate, fluoride and other elements.

Pumping a well reduces the static pressure in the vicinity of the well by an amount equivalent to the drawdown. This

reduction in pressure plus an increase in velocity of the water entering the well releases some carbon dioxide from the water and reduces the ability of the water to carry dissolved minerals in solution. Minerals such as iron hydroxide, calcium carbonate and magnesium carbonate are then deposited in the pump, in the well screen openings, in the gravel pack and on the sides of a rock well. Direct deposition of suspended matter from the water may also occur. Methods of maintaining wells will be discussed under the general heading of well stimulation.

### Well Stimulation

Stimulation is defined generally as the treatment of a well by mechanical, chemical or other means for the purpose of reducing or removing an underground resistance to flow.

With the different types of water wells and the wide variation in the composition of the deposits formed no single treatment is suitable for all wells. In most instances it would be wise for municipalities to obtain the advice and services of water well experts before embarking on a well stimulation programme.

Some methods of well stimulation which have been used for water wells will be described briefly. Table 2 outlines the application of the methods to various problems.

Table 2 - Applications of Various Well Stimulation Methods

Method	Unconsolidated Aquifers	Limestone or Dolomite Aquifers
Surging	Removes plugging deposits of clay, silt and fine sand in areas adjacent to screens	Rarely used
Jet Cleaning	Removes encrusting minerals, clay, silt and fine sand in areas adjacent to streams	Rarely used
Dynamiting	Not recommended	Effective under some conditions
Hydraulic Fracturing	Not usually used	Particularly effective in rocks with tight fractures
Acidizing	Removes iron, sulphur and carbonate deposits	Sometimes beneficial, best results obtained by pressure acidizing
Caustic Soda	Removes oil scum left by oil-lubricated pumps	Removes oil scum left by oil-lubricated pumps
Chlorination	Removes iron and slime-forming bacteria	Removes iron and slime-forming bacteria
Polyphosphate followed by chlorine	Removes fine silt, clay colloids, disseminated shale and soft iron deposits	Not usually effective

## Surging

The process of surging involves the movement of water back and forth through the formation surrounding the well in an effort to remove the fine particles clogging the walls of the well. Surging may be accomplished by the use of a surge block, compressed air, dry ice, or by starting and stopping the pump. Surging is often used in conjunction with chemicals to increase their effectiveness.

## Jet Cleaning

Jet cleaning is done by directing a high-velocity stream of water horizontally out through the openings of well screens to move the formation particles and encrusting materials surrounding the well screen. It is desirable to pump the well lightly at the same time that the high-velocity jet is operating to aid in carrying the loosened material into the well for removal. Jet cleaning may be used instead of surging in conjunction with the chemical treatment of wells.

## Dynamiting

The use of dynamite for stimulation is limited to rock wells. The work should only be done by persons qualified for the job.

A series of dynamite charges may be set off at frequent intervals along the length of the water-bearing rock or a high-velocity explosive fabricated in the form of a string may be used to produce a linear explosion along the whole length of the water-bearing rock.

A special form of dynamiting known as vibratory explosion uses a series of very small charges fired in rapid sequence to produce a vibrating effect. The explosion creates a gas bubble which expands and contracts and adds a surging action to help free the particles loosened by the vibrations of the explosion.

## Hydraulic Fracturing

Hydraulic fracturing is a new technique which was introduced into the oil industry about nine years ago and has since been used on thousands of oil wells. It consists of injecting fluid into the well under such high pressure that the rock formation is actually parted or fractured. Sand is added to the fluid and remains in the fractures propping them open permanently.

## Acidizing

This is a popular, and in many cases, an effective method of stimulating wells. It is especially well suited to the stimulation of sand and gravel wells in which the screen is encrusted with iron and carbonate deposits.

The most commonly used acid is muriatic, a commercial grade of hydrochloric acid. The concentration usually injected into the well is 15 per cent. Muriatic acid should not be used in wells containing concrete screens. An inhibiting agent should be added to the acid before use in order to delay attack on the metals in the well structure. In time the protection provided by the inhibitors is broken down so it is important that the acid should not be allowed to remain in the well for prolonged periods. Other additives for the acid include antifoam and stabilizing compounds. Stabilizing chemicals prevent the secondary precipitation of dissolved iron deposits which could plug the screen.

A saturated solution of sulfamic acid has been used recently in place of muriatic acid for acidizing wells. Sulfamic acid has the advantage that it can be shipped in a granular form and the acid solution made up at the well site. The rate of attack on metals is slower than that of hydrochloric or sulphuric acids. Nevertheless a suitable inhibitor should be used. Iron oxide scale is only partly dissolved by sulfamic acid, although the addition of sodium chloride increases the effectiveness in dissolving iron deposits.

Pressure acidizing is receiving study as a method of stimulation of water wells ending in rock or cemented overburden deposits. It consists of the introduction into the water-bearing formation of large volumes of acid at high rates of injection and pressure. Pressure acidizing can be applied only when the formation to be treated is sealed off from overlying formations.

## Polyphosphate Treatment

The use of polyphosphates for well stimulation is generally confined to sand and gravel wells. It can be used successfully for cleaning screened wells which are plugged with fine sand, silt, clays, colloids, disseminated shales and some other mineral deposits. The polyphosphates react with, and hasten the removal of, these materials. Polyphosphates can also be used to dissolve certain forms of soft iron deposits. Wetting agents may be used in conjunction with polyphosphates to improve the penetration into the formation. Polyphosphate does not readily attack the metals in wells.

Polyphosphates should not be used in the treatment of

wells with multiple screens in water-bearing formations containing layers of clay or silt as the action of the polyphosphate will cause the clay and silt to move into the sand and gravel formations, plugging them.

### Chlorination

Chlorine is sometimes used alone as a complete well treatment, but it is more frequently used as a supplement following an acid or polyphosphate treatment. A concentration of 50 ppm of available chlorine in a well provides effective disinfection, a concentration of 200 ppm destroys certain types of iron bacteria, and a concentration of 500 ppm will destroy sulphur and slime bacteria.

### Effects of Well Stimulation

Louis Koenig, who recently completed a three year study of the benefits of water well stimulation, concluded that stimulation is a technically and economically feasible practice applicable to a wide variety of wells and aquifers and that by means of stimulation additional production can be obtained from existing facilities, the investment cost per unit production can be reduced and the energy cost for pumping water can be reduced. He advocated that studies in the field of well stimulation should be greatly increased.

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ELIMINATION OF HYDROGEN SULPHIDE FROM  
DEEP WELL WATERS

by

F. A. Voege

Director, Laboratory Division - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961



## ELIMINATION OF HYDROGEN SULPHIDE FROM DEEP WELL WATERS

F. A. Voegel

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I think that most of us have encountered hydrogen sulphide or knows about it by its "rotten egg" odour. Briefly, hydrogen sulphide is a gas with a formula,  $H_2S$ . It is slightly heavier than air at a ratio of 1:1.19 and its solubility in water is .3846 gm in 100 gms of water at 20°C and 760 mm mercury air pressure. It acts like most normal gases, that is, its solubility decreases with increase in temperature of the solution in which it is dissolved.

### Formation

Hydrogen sulphide is found in well supplies more often than in surface supplies. It occurs in waters through the action of carbon dioxide dissolved in the water dissolving the soluble sulphides, or the water may form other compounds with the sulphide and form hydrogen sulphide. Hydrogen sulphide is also formed by the action of seepage water on coal beds. Sulphide may be formed by the action of certain species of sulphur bacteria on sulphates. Various other anaerobic bacteria can break down organic matter directly into its more elementary compounds, one of which may be sulphur. Location of wells near Boulder Clay areas or "Sour Gas" oil fields often is the cause of hydrogen sulphide in the water.

### Effects

Hydrogen sulphide gas is poisonous and acts similarly in this regard to carbon monoxide and hydrogen cyanide. The United States Public Health Service limits the concentration of hydrogen sulphide gas to 20 ppm, which corresponds to 0.027 mg of hydrogen sulfide per litre of air, in areas where there will be an 8-hour exposure period. In water however, hydrogen sulphide is not toxic and often waters containing it are used as health drinks.

Hydrogen sulphide's characteristic odour of rotten eggs is one of the effects by which it is known best. This odour is claimed by Nordell (1) to be noticeable even at low temperatures, when the sulphide concentration is 0.5 ppm or more. Less than 0.35 ppm, however, will cause few people to complain of its presence. At concentrations of 150 ppm the

odour will affect the sense of smell so that after 15 minutes exposure this sense will be incapable of detecting the presence of hydrogen sulphide. If the pH is raised to 9.0 or more most of the sulphide odour will disappear due to the conversion of the hydrogen sulphide to alkaline sulphides. At pH 5.0, 98 per cent of the sulphides present are available as hydrogen sulphide, whereas at pH 9.0 only 0.5 per cent is available as hydrogen sulphide. At neutrality, or pH of 7.0, 33 per cent is available as hydrogen sulphide.

Hydrogen sulphide will react with corrosion inhibitors such as chromates and nitrites used widely in industrial cooling water systems and increase their consumption thereby increasing the cost of corrosion control.

Hydrogen sulphide in solution reacts with the iron or steel in water mains to form suspensions of black iron sulphides, causing a corrosion and "black water" problem. It is also aggressive toward copper, copper alloys, and galvanized piping even in the absence of oxygen. The reaction products of the hydrogen sulphide and the pipe materials stain tubs, sinks, kitchen ware and soon clog screens or cloth filters placed on taps. Laundered clothing also becomes impregnated.

Special minerals used for the catalytic removal of iron and manganese from water are adversely affected by the presence of hydrogen sulphide. The absence of hydrogen sulphide in water is generally one criteria necessary to obtain proper removal with these materials.

Cation - exchange softeners may become clogged or the exchange material incrustated. An article in The Betz Indicator mentions that cases have been reported where greensand zeolites have been so badly attacked in a few months by water containing as low as 2 ppm of hydrogen sulphide that the bed could not be reconditioned.

## METHODS OF REMOVAL

Various methods have been tried, and used, some successfully others not. Eight methods that can be used are listed below:

1. Aeration in elevated tanks.
2. Atmospheric aeration using natural-draft ventilation, in conjunction with ground storage reservoirs.
3. Atmospheric aeration using forced draft ventilation in conjunction with ground storage reservoirs.
4. Atmospheric aeration, either natural or forced-draft, together with pH reduction.

5. Atmospheric aeration, using weirs or steps before ground storage reservoirs.
6. Aeration with compressed air in hydropneumatic tanks.
7. Chlorination.
8. Anion exchange method.

The first six methods deal primarily with the use of aeration and will be discussed first as a group.

The sulphides are present either in the form of metallic sulphides and/or hydrogen sulphide gas and most removal methods employ some form of aeration. The removal of hydrogen sulphide by aeration follows Henry's Law. This states that the mass of a slightly soluble gas that dissolves in a definite mass of a liquid at a given temperature is very nearly directly proportional to the partial pressure of that gas. Hydrogen sulphide is relatively soluble in water while the partial pressure of this gas in the normal atmosphere is practically zero. The basic fundamental in securing removal of gases from water by aeration is the establishment of a state of equilibrium between the gases in the water and the gases in the surrounding atmosphere. Therefore, it is necessary that the gas be allowed to dissipate as fast as possible into the surrounding atmosphere. Since it has been found practically impossible to remove all of the sulphides by aeration alone these methods were often followed by other forms of hydrogen sulphide removal.

#### AERATION IN ELEVATED TANKS

This method was used in three systems in Florida. At one system the riser pipe was carried across the tank just above the overflow point and terminated in a sealed end. Holes 1 inch in diameter on 12-inch centres extended across the upper surface of the pipe. A tee with open end facing upward was in the centre of the cross arm aerator. A 12-inch wide, plastic-screened opening in the tank wall at aerator level provided ventilation. Detention in the tank was estimated to be 275 minutes resulting in 90 per cent removal of sulphides.

In a system such as this the reduction of dissolved sulphides appears to be effective if the detention period is on the order of  $2\frac{1}{2}$ -3 hours.

Care must be taken to keep the tank clean of precipitated sulphur, sulphur compounds, sulphur bacteria and iron sulphide.

## ATMOSPHERIC AERATION USING NATURAL-DRAFT VENTILATION

These aerators are usually of the slat tray type, with or without coke, crushed stone or similar materials. Adjustable spray nozzles are also used.

The design loading of 5 - 10 ppm was found useful in Florida in reducing the sulphide content of artesian water. However, the reduction was only 35 - 45 per cent. After the slat tray aerators the use of ground storage reservoirs with a detention period of 1 - 2 hours was stated to give complete removal of dissolved sulphides under the existing conditions in Florida.

Maintenance of the open tray aerators involves occasional scrubbing of trays and aerator floor to remove algae, bacteria, precipitated sulphur and sometimes bloodworms which are the larval stage of midge flies.

## ATMOSPHERIC AERATION WITH FORCED DRAFT VENTILATION

This is similar to the preceding method except for the way of bringing the air in contact with the water. This type of aeration has been found desirable where there is an appreciable hydrogen sulphide concentration to be removed. The literature states that it is desirable to have a tall tower with considerable cross-sectional area. With this equipment, hydrogen sulphide can be reduced to 1 - 2 ppm.

## ATMOSPHERIC AERATION, EITHER NATURAL OR FORCED DRAFT, TOGETHER WITH pH REDUCTION

As mentioned before, complete removal of hydrogen sulphide is generally not obtained by aeration alone. At higher pH values the sulphide content will be present chiefly as alkaline sulphides and incomplete removal will result. If carbon dioxide was present originally, it was driven off by aeration before the hydrogen sulphide was and the pH value rose.

Removal of hydrogen sulphide by aeration is most effective at reduced pH in the range of 4 to 5 because more of the total sulphide is converted to hydrogen sulphide in which form it is available for removal by aeration.

The reduction of the pH can be accomplished by the addition of mineral acids or scrubbed flue gases. Flue gases which are high in carbon dioxide content have been employed in recent years. The quantity of gas required will depend upon the alkalinity of the supply being treated.

The article in the Betz Indicator (2) describes one type of equipment for this process. This consists of a double stack with a water seal separating the upper carbonating chamber from the lower aeration chamber. The flue gas is introduced at the bottom of the carbonating chamber and mixes with the influent water flowing down that chamber. Most of the hydrogen sulphide is removed at the reduced pH in the upper section. In the lower section, which is similar in design to the carbonating chamber, the counter-current of air provides additional scrubbing of the water with air alone for the removal of carbon dioxide and further removal of any residual hydrogen sulphide. The taller the tower the greater the contact time provided.

Mineral acid can also be used to reduce the pH and the addition of this can be used to give more positive control.

#### AERATION WITH COMPRESSED AIR IN HYDROPNEUMATIC TANKS

The air enters the tank with the water through a nozzle or jet or through a grid system within the tank. The tanks used usually vary in capacity from 1,500 to 3,000 gallons although they have been used up to 12,000 gallons. The unoxidized hydrogen sulphide gas released in the tank, along with excess air is bled from the tank through air relief valves.

It is believed that the oxidation of the dissolved sulphides through the sulphur stage to alkaline sulphates occurs rather rapidly in this type of system. This seems to explain the lack of intense hydrogen sulphide odour from the air relief valves and the general absence of precipitated sulphur in the tank.

One author Flentje (3) states that the amount of air required is from 0.005 to 0.16 cu.ft. per U.S. gallon of water and that a short detention period usually approximately 15 minutes is recommended. Another author Roe (4) states that a detention time longer than 20 minutes is probably unnecessary and the estimated power required averages 1.0 KW for 1 million U.S. Gallon per day capacity. Even with this type of aeration some systems still encounter milky water. Higher air to water ratios may be objectionable due to entrained air causing milky water and increasing corrosion of metallic mains, meters and fittings. Pressure aeration is not recommended for water supplies also containing appreciable amounts of carbon dioxide since this chemical is only slightly removed.

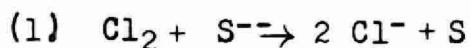
In a number of wells using this method that were studied by Wells (5) hydrogen sulphide concentration ranged from 2 to 1.0 ppm and removal ranged from 85 to 35 per cent. Detention ranged from 80 to 16 minutes (figures which vary somewhat from those suggested previously), maximum operating pressures were from 68



to 36 psi and air to water ratio was 0.01 - 0.02 cu. ft. per gallon.

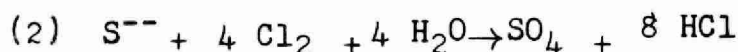
## CHLORINATION

Up to this point I have confined my discussion to removal of hydrogen sulphide and sulphides by various forms of aeration including using pH adjustment. While these methods will reduce the hydrogen sulphide to a relatively low concentration depending on the initial content, they will not reduce it to zero which may be necessary depending on the use to be made of the water. Complete removal of hydrogen sulphide from water can be obtained by chlorination or aeration and chlorination combined. Chlorine is usually chosen as the oxidizing agent to complete the removal by oxidizing the metallic sulphides and hydrogen sulphide to free elemental sulphur. This occurs in the primary reaction that is shown in the following equation:



For this reaction for every ppm of sulphide present 2.1 ppm of chlorine are needed. The sulphur formed is a fine colloidal precipitate and should be removed by coagulation and filtration to prevent reversion to hydrogen sulphide by the action of certain micro-organisms.

Theoretically, when the ratio of chlorine to sulphide present is increased the hydrogen sulphide should be oxidized to sulphuric acid without the precipitation of the sulphur. This is shown in the following equation:



For this reaction, 8.4 ppm of chlorine are needed for 1 ppm of sulphide.

These two equations show that the only sulphurous end products are sulphur and sulphate. Their ratio depends upon such factors as relative concentrations of original reactants, pH, standing time and rate of addition of reactants.

Carefully controlled experiments conducted by Goodson and reported by Black and Goodson (6) indicated that different concentrations ranging from 2 to 6 ppm hydrogen sulphide had no effect on the extent of the reaction. These experiments showed that the ratio of chlorine to sulphide reacted increased in all cases with an increase in the ratio of chlorine added. Ratios used were from 2 to 10 times the weight of sulphide ion present. The increase in

the ratio of chlorine to sulphide reacted was quite substantial in acid solutions, but it became less marked as the pH of the medium was increased. Results of the experiments indicate that the initial oxidation process proceeds only as far as free sulphur in acid solutions and somewhat beyond that stage in neutral to alkaline solutions. Also, it was shown that temperatures had no effect on any of these reactions. Goodson observed from his experiments that there must be a process whereby a portion of the free sulphur is oxidized simultaneously to a higher oxidation state which was shown previously by other investigators to be sulphate. According to him the results of the investigation show that from the standpoint of water works practice pH is by far the most important variable studied, since it exerts such a considerable influence on the dosage of chlorine required to insure complete sulphide removal. For example, it is estimated that about 4 mg of chlorine per mg of sulphide were required to produce a slight chlorine residual at pH 8, whereas 7.5 mg were necessary at pH 5. This variation actually reflects the effect of pH on the secondary process that produces sulphate. Thus, although lower pH requires higher chlorine dosages for sulphide removal, it yields correspondingly larger sulphate to sulphur ratios in the reaction mixture. This information can be useful in determining the most advantageous cost between adjusting aeration, pH, chlorination and following treatment.

The variable next in importance from the water works operation standpoint is the effect of reaction time. Although the initial reaction by which sulphide is eliminated has been found to take place immediately upon the addition of an excess of chlorine, the secondary oxidation of sulphur has been found to progress with time. Use may be made of the maximum rate of this secondary oxidation, which has been found to occur in the pH range of 6.5 to 7.3. This increased reaction rate indicates that by allowing a longer reaction time, it is possible to accomplish, at a higher pH, the same degree of oxidation in the reaction mixture that can be accomplished at a much lower pH and a shorter reaction time using the same chlorine dosage.

Thus, by using the best combination of aeration, pH adjustment and chlorine usage a good treatment method can be achieved.

#### ANION EXCHANGE METHOD

Highly basic resins have been prepared for ion exchange adsorbers which, when regenerated with salts and/or sodium bicarbonate depending on the pH of the water, exchange their ions for sulphides, sulphates, etc. The reaction is as follows:



In this process a low cost regenerant is employed, line pressure is not broken, excess oxygen is not added to the water and a minimum of equipment is needed. Up to 1956 the use of highly basic anion resins for hydrogen sulphide removal had been limited to domestic uses although they could be satisfactory for some industrial uses.

The limitations of this method are low capacity, low flow rates, iron must be absent from the water and it is preferable for the influent water to be low in hardness.

#### DETERMINATION OF HYDROGEN SULPHIDE

In all the tests on the efficiency of sulphide removal the concentration must be known. Three methods can be used:

1. Titration method in which a standard iodine solution is reduced by the sulphide and the residual iodine is titrated with standard sodium thiosulphate solution in the presence of starch indicator. The disappearance of the blue colour is taken as the end-point.
2. Colourimetric procedure is also available in which para-amino dimethylaniline and ferric chloride react with sulphide to form methylene blue. The colour developed is compared with standard methylene blue solutions.

The above two methods are described in much greater detail in the 11th Edition of Standard Methods for the Examination of Water and Waste Water.

3. Treated Paper Test which uses an impregnated paper exposed to hydrogen sulphide fumes evolved from sample. Dark spot on paper is compared with standards.

#### SAMPLING

With any method care in sampling is most important. The water sample should be obtained with as little air contact as possible. Because of the loss of hydrogen sulphide on standing or in transit, tests should be conducted within a few minutes after obtaining the sample at the point of sampling.



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IRON REMOVAL & WATER SOFTENING  
IN DEEP WELL SUPPLIES

by

P. G. Cockburn

Assistant District Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
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# IRON REMOVAL & WATER SOFTENING IN DEEP WELL SUPPLIES

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## INTRODUCTION

Iron and hardness are two of the most troublesome impurities in water supplies, iron because of the staining which results and hardness because it wastes soap and forms scale.

The tolerance for iron in municipal water supplies is usually stated at 0.3 ppm. which is only a very small fraction of the usual recommended tolerance for hardness.

If the concentration of iron exceeds 0.3 ppm. staining becomes a serious problem, for then the bathtub, washbowl and other porcelain fixtures develop unsightly rust-brown or black stains. Iron also stains glassware and tiled floors. Laundering in iron-bearing waters presents an extreme staining problem and in many cases is impossible. Also, if the iron content is 1 ppm. or greater the water possesses an unpleasant metallic taste. The problem of iron deposits in water supply distribution systems is also common with iron-bearing waters.

Iron is found principally in ground waters from wells in shale or sandstone, or from shallow wells in alluvial deposits in swampy areas and in surface waters flooding such areas.

Hard waters are expensive nuisances. They waste tons of soap; decrease the life of washable garments; scale water heaters, boilers, hot water piping; and increase costs for fuel, labour and replacements. Surveys have shown that, on the average, the costs of the materials used in softening a municipal water supply are only about one-third of the cost of soap wastage incurred in using hard water.

## WATER SOFTENING

### INTRODUCTION

As a result of the dissolving action of water, most natural waters contain various amounts of the common mineral compounds, particularly those including calcium and magnesium. It is the presence of these metals which causes water to be hard, the degree of hardness being directly proportional to the concentration of the metal salts.

Hardness is of two kinds, carbonate hardness, sometimes called temporary hardness because part of it is removable as scale by boiling; and non-carbonate hardness, also called permanent hardness because it is not effected by boiling. Carbonate hardness is due to calcium and magnesium carbonates and bicarbonates. The calcium carbonate is insoluble except for a residual of approximately 1-2 gpg., so that partial softening is obtained by changing these bicarbonates to carbonates. Non-carbonate hardness is caused principally by calcium and magnesium sulphates and chlorides.

There are two principal methods of water softening on a municipal scale - the lime or lime-soda process (precipitation) and the cation exchange process. Smaller plants are likely to use the latter process.

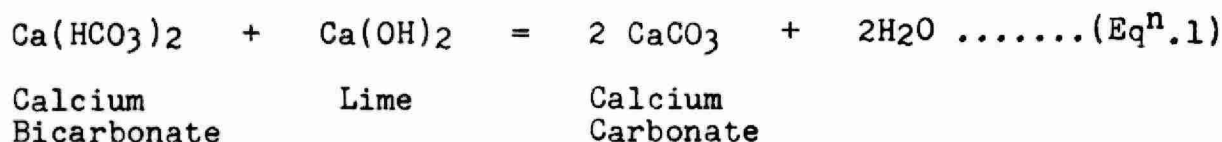
## HOW CHEMICALS SOFTEN WATER

As previously noted, the carbonate hardness is due to the presence of calcium and magnesium bicarbonates and carbonates. The calcium carbonate is soluble only to the extent of 20-30 ppm. In excess of this amount, the calcium carbonates are insoluble and will precipitate and settle out. By changing the bicarbonates to carbonates, carbonate hardness can be reduced to about 30-50 ppm.

## LIME-SODA SOFTENING

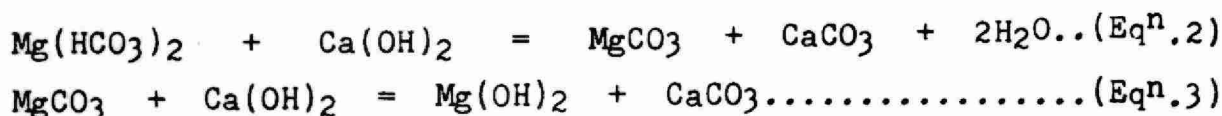
The above process can be accomplished by adding lime (calcium hydroxide) which combines with the CO<sub>2</sub> in the bicarbonates and converts them to normal carbonates.

This reaction is given as:



The reaction is the same for magnesium, however, since the magnesium carbonate is soluble, it is converted to magnesium hydroxide by the addition of more lime.

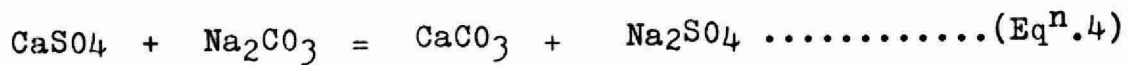
The reaction is:



Therefore, it takes approximately twice as much lime to

remove a given amount of magnesium bicarbonate hardness as it does to remove an equal amount of calcium bicarbonate hardness.

Non-carbonate hardness can be removed by adding soda ash (sodium carbonate) which reacts with the soluble non-carbonate compounds of calcium and magnesium, to precipitate out insoluble calcium and magnesium compounds but leave non-soap consuming sodium compounds in solution, i.e.,



The physical operations in the lime-soda process are similar to those in the conventional coagulation-sedimentation-filtration process for bacteria and turbidity removal.

### Recarbonation

Lime softening leaves water supersaturated with calcium carbonates. Consequently, carbon dioxide may be added to the water prior to filtration in order to dissolve any calcium carbonates which have remained in suspension and thus prevent its deposition on the sand grains in the filter or in pipes of the distribution system. In connection with this, a dose of alum may be added in the sedimentation basin. This will not only assist sedimentation but also, the carbon dioxide generated will react with the excess calcium carbonate to hold it in solution.

It should be noted that better coagulation and bacterial removal is usually effected in a lime-soda softening plant than in a simple coagulation and filtration plant because the precipitate formed may bulk from ten to twenty times as great as obtained by the ordinary coagulation process,

### Disposal of Lime Softening Sludge

The disposal of the large quantities of sludge formed by the softening reactions is sometimes a problem, especially where a softening plant is built along a small stream. It is reported that at some older plants it has been the custom to allow the sludge to accumulate in the settling basins and to discharge it intermittently. This is unsatisfactory because (1) decreases settling capacity, (2) produces unsightly condition in stream.

The newer plants are now provided with devices for continuous removal of the sludge.

Part of the sludge may be returned with advantage to the mixing tank chamber as the intimate contact of the solid phase with the supersaturated solution of carbonates and hydroxides establishes equilibrium more rapidly.

The contact softeners were developed with the object of obtaining maximum benefit from this contact with previously formed precipitates.

Where a large stream is not available for sludge disposal the sludge may be lagooned.

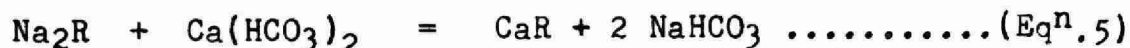
### ION EXCHANGE SOFTENING

There are two general types of ion exchange materials; those that remove dissolved elements carrying a positive charge (eg. Ca, Mg, Na) which are called cation-exchanged ions, and those capable of removing negatively charged ions (Cl, CO<sub>3</sub>) which are called anion-exchangers.

Cation-exchangers are of importance in municipal water softening, whereas the anion exchangers are used for complete demineralization of waters. For our purposes we will deal only with the cation exchangers

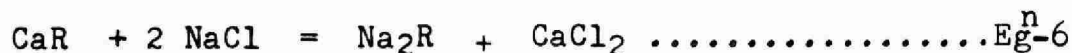
In general terms, cation or zeolite softening removes calcium and magnesium ions from the waters and replaces them with other ions, usually sodium, which do not cause hardness.

The softening action is one of replacement or exchange and might be represented by:



Here we have permitted the symbol "R" to represent the complex replaceable part of the cation exchange substance (Na<sub>2</sub>R). Note that the calcium ions have been concentrated and held on the cation exchanger. They are held in the exchanger while the sodium bicarbonate (NaHCO<sub>3</sub>) which is soluble passes out in the softened water. A similar reaction occurs for magnesium and not only includes the bicarbonates but also the sulphates.

A cation exchanger has the ability to remove 2500 to 35,000 grains of hardness per cubic foot of exchange material before it is exhausted and requires regeneration. The exchange capacity varies with the type of material used. The sodium-cation-exchanger is regenerated with NaCl as shown below:



The CaCl<sub>2</sub> produced is wasted to the sewer during the regeneration cycle.

Some cation-exchangers are operated on the hydrogen, rather than sodium cycle and are regenerated with acid.

Zeolite is placed in filter units just like filter sand. Normally pressure filters are used to permit factory construction

of standardized units. Open gravity filters may be used however.

The depth of zeolite material is usually between two and six feet.

Under normal operation, the effluent from a zeolite softener will have a hardness of zero until its exchange capacity is approached. Consequently, a test for hardness is used to warn the operator when regeneration is necessary. The volume of water which may be treated to zero hardness may also be calculated beforehand.

Water of zero hardness is corrosive and is softer than desirable for ordinary use. It is common practice therefore to bypass enough unsoftened water around the unit to increase the hardness of the final effluent to the desired value, usually between 60 and 80 ppm.

## IRON REMOVAL

### OCCURRENCE

In different iron-bearing material water supplies, the iron may be present in one or more of the following four forms:

1. Soluble ferrous bicarbonate
2. Soluble ferrous sulphate
3. Soluble organic iron
4. Suspended insoluble ferric hydroxide

In selecting a method for iron removal, it is necessary to consider the form in which the iron is present, and if, due to corrosion or iron pickup, to devise methods of stopping the contamination.

### FERROUS BICARBONATE

In iron-bearing, clear, colourless, deep well or spring waters which contain bicarbonate alkalinity, the iron is always present as ferrous bicarbonate, a colourless salt existing only in solution. This chemical may dissolve, in cold waters with  $\text{CO}_2$  and no dissolved oxygen, to the extent of 150 ppm. expressed as iron. However, most alkaline, iron-bearing ground waters fortunately contain much less than this and in fact the majority of iron-bearing wells will contain less than 5 ppm.

Most of the deep well supplies containing ferrous bicarbonate are clear and colourless when first drawn. However, in standing in contact with air, they first develop a whitish haze which gradually darkens and precipitates yellowish-brown to



reddish-brown ferric hydroxide.

This is the insoluble material which stains and discolours virtually everything with which it comes into contact.

## REMOVAL PROCESS

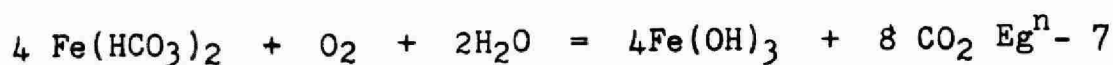
Iron, in municipal water supplies, when present as ferrous bicarbonate may be removed by:

1. Aeration, settling & filtration
2. Cold-lime-soda process
3. Zeolite process

### Aeration, Settling & Filtration

When ferrous bicarbonate is oxidized, it is transformed into the practically insoluble ferric hydroxide:

ie.



This oxidation can be effected by either air or chlorine and, since the latter has to be purchased while the former is free, air is most widely used. In addition to being cheaper, aeration has the added advantage of reducing the free carbon dioxide content of the water and raising its pH value.

This oxidation with air proceeds rapidly at a pH of 7.0 or over. With waters having a sufficient content of bicarbonate alkalinity, aeration alone is sufficient to raise the pH above 7.0 and effect rapid oxidation of the iron. Theoretically 7 ppm. of iron will be oxidized by 1 ppm. of oxygen.

While the oxidation of ferrous bicarbonates by oxygen is best carried out at a pH of 7.0 or above, chlorine will effect a complete oxidation at a pH as low as 5.0. The amount of chlorine required is 1 ppm. to 1.6 ppm. of ferrous iron. However, chlorine presents some advantages at lower pH values when the content of iron is rather low or, in some cases, as a secondary treatment when the bulk of the iron has been removed by aeration.

Several types of aerators are used and a brief description of the most common forms is given below:

#### A. Coke Tray Aerators:

These units consist of a series of coke filled trays through which water percolates with additional aeration supplied during the free fall from one tray to the next.



## B. Wood Slat Tray Aerators:

These units are similar to small atmospheric cooling towers. The tray slats are staggered so as to break the free fall of water and to spread out the water surface before finally dropping into a basin.

## C. Forced Draft Aerators:

These units are more common in industrial water conditioning plants. They consist of a series of horizontal wood slat trays which divide the falling water into small streams. Air is forced up through the unit by a blower with uniform air distribution across the entire cross section.

## D. Air Diffusion:

Air diffusion is accomplished by pumping air into water through perforated pipes, strainers, porous plates or tubes.

Following the aerator, a settling basin is normally provided. These vary in size, but the detention period should preferably be greater than 30 minutes. However, with waters containing small concentrations of iron, settling tanks and with 15 minutes retention are not uncommon.

The next step is filtration by either gravity type or pressure type filters.

## 2. Lime-Soda Process

Since many iron bearing municipal water supplies are also hard waters, the lime soda process is used for simultaneous iron removal and water softening. The removal is excellent for, at the high pH values prevailing, the oxidation of the insoluble hydroxide is quite rapid.

The equipment consists of (i) aerator, (ii) chemical feeders, (iii) settling tanks, (iv) filters. Settling basins of the solids contact type are used in many cases for this purpose and a later lecture will be devoted to these units.

The chemical feeders are for feeding lime, soda ash (if required) and a coagulant such as alum. From the sedimentation unit the settled water passed to the filters and then to the clear water well and service.

It should be noted that if the concentrations of iron are great, it may be possible to eliminate the use of another coagulant since the precipitated ferric hydroxide will floc the calcium carbonate and magnesium hydroxide precipitates forming an easily settled large floc.

### 3. Zeolite Process

Iron, present as ferrous bicarbonate, can also be removed with hardness by passing the water through a zeolite water softener. Therefore, if a ground water is to be softened and also have an undesirable concentration of iron removal, the zeolite softener offers a simple solution to both problems. In some cases these units have been used primarily for iron removal purposes with water softening being of incidental importance. However, the units are not practical for iron removal without any softening.

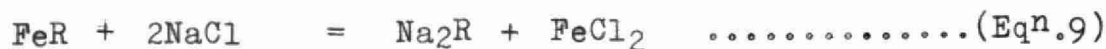
When operated on the sodium cycle, iron removal takes place as follows:



Ferrous  
Bicarbonate

Sodium  
Bicarbonate

On regeneration, the iron is liberated as ferrous chloride.



It is the usual practice to limit the application of the cation exchange unit to waters with not greater than 1 ppm. iron to each 2 gpg. of hardness.

The manganese zeolite process removes iron from water but it does not soften it. The process is limited to waters which do not contain over approximately 1 ppm. of iron.

The process is termed contact filtration and is accomplished simply by filtering the water through the manganese zeolite which serves to both oxidize the iron to an insoluble form and to filter these forms out of the water. Periodically, the accumulations are removed by back-washing the filter and the manganese zeolite is regenerated with a solution of potassium permanganate.

#### FERROUS SULPHATE

Ferrous sulphate is found only in acid waters and these waters usually originate in mining districts. The usual treatment is aeration; neutralization with lime, soda ash or caustic soda; settling; and filtration. Many of these acid waters, particularly the ground waters have part or most of the iron present as ferrous bicarbonate. In many instances this is due to the passage of the water through limestone strata which neutralizes most of the free sulphuric acid and some of the ferrous sulphate to form calcium sulphate, carbon dioxide and ferrous bicarbonate.

If softening is also required, the cold lime-soda process is used.

#### ORGANIC IRON

In many high coloured waters, iron may be present in an

organic form. This is mostly confined to surface supplies from swampy areas but an occasional deep well may yield water containing iron in this form.

Aeration is not wholly successful in removal of this form, and in some cases no effect is produced. Chlorination and zeolite treatment also are of little value in this respect.

Coagulation, settling, and filtration will however effect removal with alum the most common coagulant used (pH 5.5-6.8).

#### FERRIC HYDROXIDE

Suspended ferric hydroxide will be found in iron bearing waters, where it was originally present as ferrous bicarbonate. First, if from a shallow well and second, if the water is pumped by means of an air lift. In these cases the ferrous bicarbonate has been oxidized by the air. Some of this may precipitate in the well whereas another portion is carried into the mains.

Usually both ferrous bicarbonate and ferric hydroxide are present since the amount of air available for oxidation is limited. Therefore, the first step in treatment is to effect a complete aeration of the water. Then the entire iron concentration of iron can be removed by settling and filtration. It is possible, and perhaps more likely, that if an air lift is used complete oxidation can occur in the well. In this case, only sedimentation and filtration is necessary.

#### IRON BACTERIA

The presence of iron bacteria may also be encountered in iron bearing waters. These filamentous organisms are not true bacteria but represent a somewhat higher form of plant life. They are characterized by the presence of iron on the surface or within their gelatinous sheath. The most common of these organisms is known as Crenothrix although the term iron bacteria also includes several other species. These bacteria develop in clumps or as slime attached to the walls of distribution pipes and they may be present in reservoirs and stagnant ponds as well as ground water supplies.

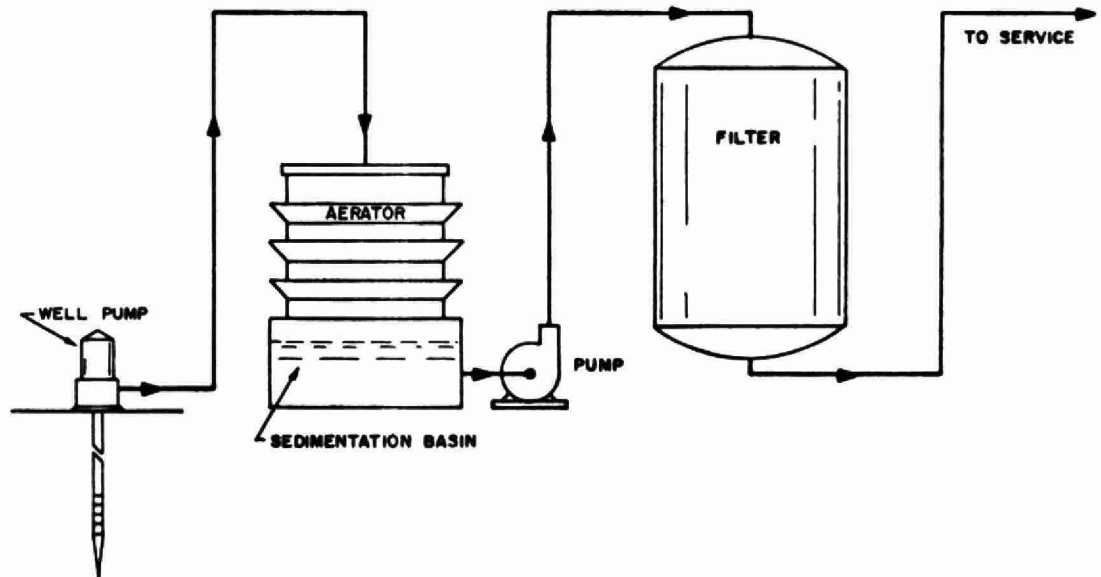
Complaints reporting small gray or brownish flakes, masses of stringy or fluffy growths in water would indicate the presence of iron bacteria.

Although the presence of organic matter is necessary for their growth, light and oxygen are not essential since some organisms are prominent in dark waters deficient in oxygen.

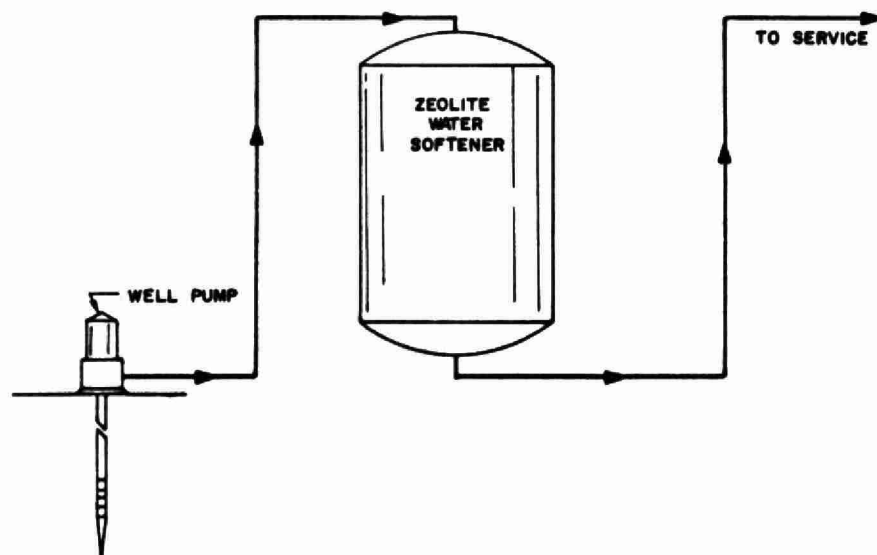
Since an accumulation of iron bacteria is undesirable,

the condition usually can be corrected by removing iron from the water before it enters the distribution system, and thereby depriving the organisms of food. Also, removal of organic matter and increasing dissolved oxygen (to 2 ppm.) has proven effective in preventing growth.

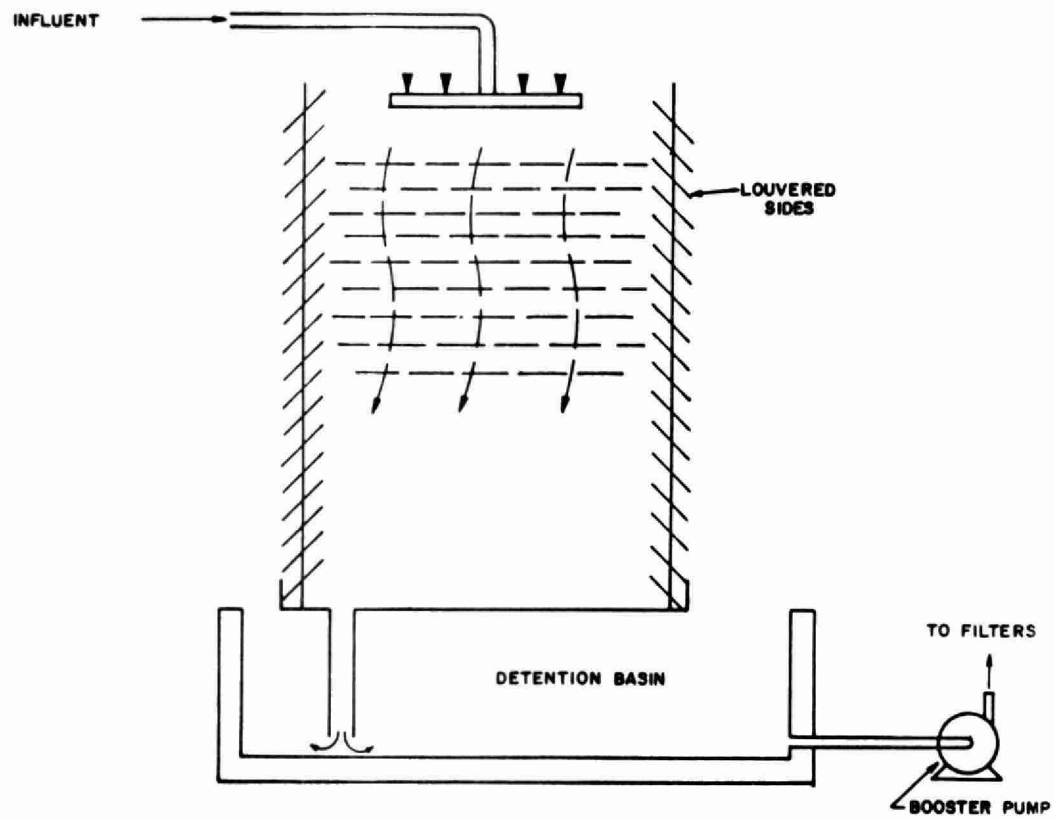
### AERATION SETTLING AND FILTRATION



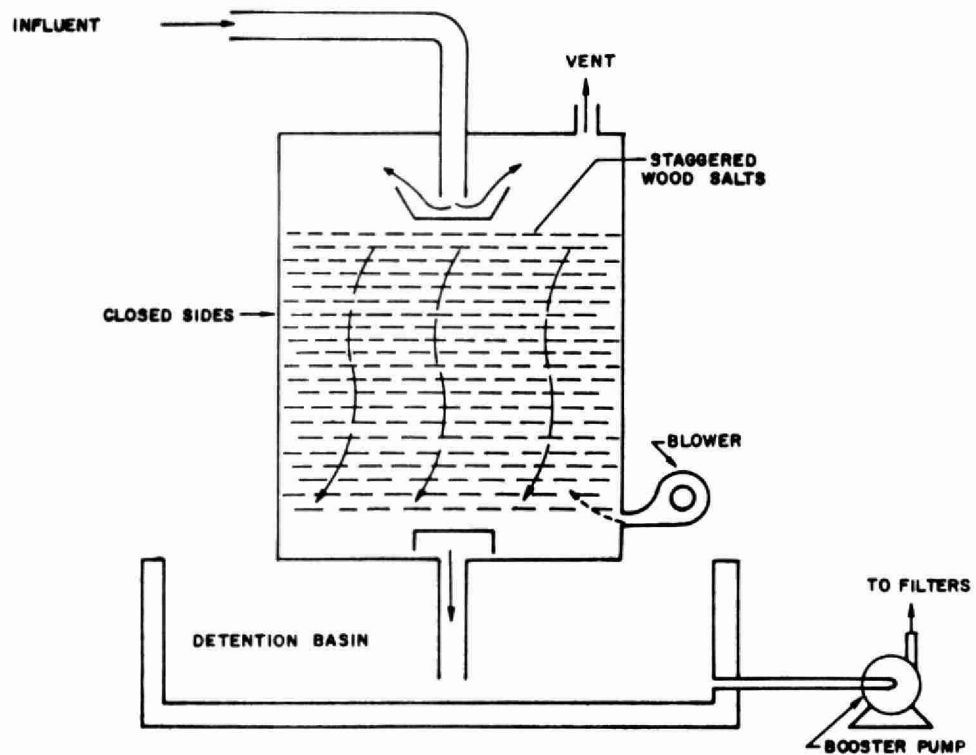
### ZEOLITE WATER SOFTENER



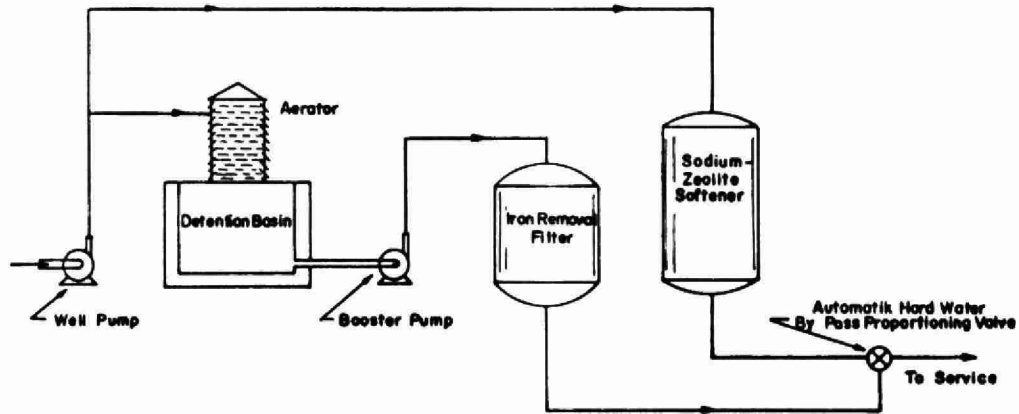
### OPEN SLAT - TRAY AERATOR



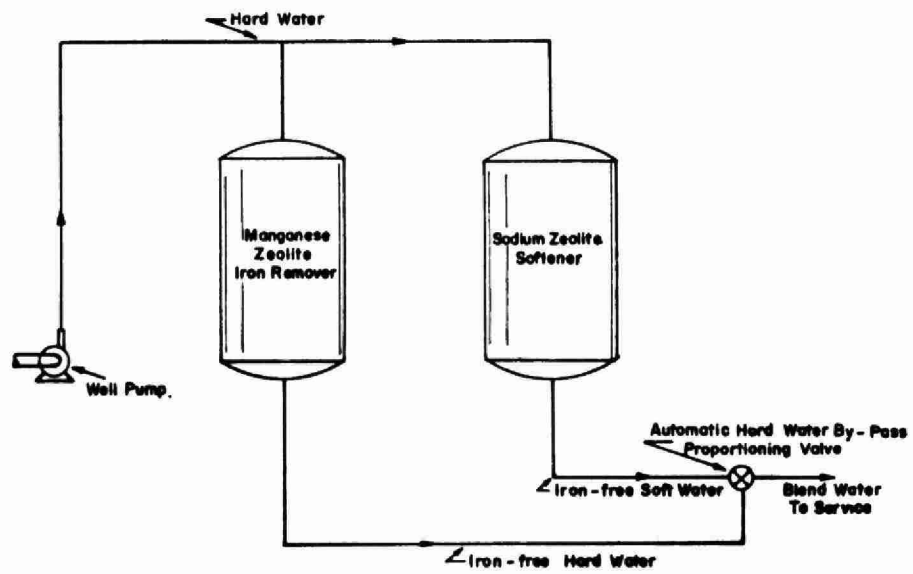
### CLOSED FORCED DRAFT AERATOR



## SODIUM ZEOLITE SOFTENING COMBINED WITH IRON REMOVAL



## MANGANESE ZEOLITE METHOD OF REMOVAL COMBINED WITH ZEOLITE SOFTENING



PROBLEMS IN FILTRATION

by

G. M. Galimbert

Assistant General Manager - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961



## PROBLEMS IN FILTRATION

G. M. Galimbert

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Filtration is one of the two major treatments in any modern water works plant. It has, therefore, been thought desirable that in this second course that the information provided in this field should be continued. In the original course of lectures, problems in connection with filters were discussed in a general way. Now, factors involved in specific problems will be covered in more detail. These include back washing operations, production of "mud ball" conditions, shifting of gravel, air binding and break-throughs.

### BASIC PRINCIPLES IN OPERATING FILTERS

There are certain basic principles that must be adhered to if a filter is to be operated in a proper manner and it is to be kept in proper condition. Raw water conditioning ahead of filters should be carried out properly. Every effort should be made to have the water going on the filters of a constant quality no matter what the condition of the raw water. Do not make the filter do the main job of improving the quality of the water. In fact, the water applied to the filter should not have a turbidity in excess of 10 p.p.m. as excessive turbidity applied to filters produces short runs, promotes "mud ball" formation and tends to cause cracking of the sand surface. It also must be emphasized that over-treatment with coagulants should be avoided. There must be some floc reaching the filter if the treatment is to be effective. It is also true that excessive washing may cause difficulty. Sampling of the individual filters from a bacteriological standpoint is also desirable. On occasion, it may even be necessary to disinfect the filter bed with a strong chlorine solution if tests indicate that it is necessary to eliminate bacterial conditions. With that preamble on the operation of the filter, individual problems will now be covered in more detail.

### BACK WASHING OF FILTERS

Back washing of a filter is perhaps the most important operation in maintaining a plant in good operating condition. If this operation is not carried out properly, at the correct time interval and with suitable facilities, it may cause many problems in the maintenance of the filters. There are many factors that enter into proper back washing of a filter.

These include the size and the condition of the sand or anthra-filt and gravel in the bed, the temperature of the water, the underdrains, the rate and manner of application of the wash water, the surface water facilities available and the capacity and location of the wash water troughs.

#### BACK WASHING SHOULD BE CARRIED OUT AT PROPER INTERVALS

It is essential that the back washing operation be carried out at intervals that will assure that the filter media is kept in a satisfactory condition. This will be determined by experience in individual plants but as a general rule, it should be carried out when the loss of head equals the distance from the water surface on the filter to the bottom of the filter or whenever the effluent shows turbidity and is no longer satisfactory. Loss of head on sand filters will be between 6 and 8 ft. when back washing is required. It may only be 2 to 3 ft. in filters with anthrafilt media. In some filter plants, where the operation is not continuous, it is common practice to back wash the filter at the end of the day's run or before the start of the next day's operations.

#### MANNER OF FILTER WASHING

Filter washing is accomplished by closing the influent valve with the effluent valve open so as to draw the water down until the level is about one ft. above the sand. The effluent valve is then closed and the wash water drain or sewer valve opened. Wash water is then applied by opening the wash water valve slowly. After washing for the required time, which can range from 4 to 8 minutes, the wash water valve is closed. The wash water drain valve is closed after the dirty water in the gutters is gone. The influent valve is then opened allowing the filter bed to fill up. The effluent valve is opened slowly and the filter is again put in operation. There is no necessity to waste filtered water after the back wash cycle has been completed.

#### EXPANSION OF SAND IN BACK WASHING

Back washing should be rapid enough to expand the bed about 30 per cent although many authorities indicate that satisfactory back wash cannot be secured with less than 50 per cent expansion. The appearance of clear spots in the rising wash water is generally an indication that the wash has been sufficient. While there can be a wide variation in the amount of back wash water used, it should not be greater than 2.5% of the filtered water. An operator will readily become proficient in determining when the back wash cycle has been completed.

## BACK WASH RATE VARIES WITH EFFECTIVE SIZE AND SPECIFIC GRAVITY OF MEDIA

The back wash rate required will vary for different effective sizes and specific gravities of the filter media. The usual wash rate for sand approximates 15 gals./sq.ft./min. or  $7\frac{1}{2}$  times the filter rate. On the other hand, the wash rate for anthrafilt will approximate 7.5 gals./sq.ft./min. or almost four times the filter rate. There are filters with a combination of anthrafilt over sand media that require a rate just below that necessary for the sand media wash.

## BACK WASH RATE VARIES WITH TEMPERATURE OF WATER

The back wash rate will also vary with the temperature of the water. About sixty per cent more water is required to back wash a filter with water at 70°F. than at 32°F. Back wash rates as high as 20 g.p.m./sq.ft./min. may be required in the summer.

## SURFACE WASH INSTALLATIONS

In recent years there have been two surface wash devices made available to assist in washing filters. There are the Palmer sweep and the Baylis fixed jet surface washers. The fixed jets are spaced 24 to 36 inches apart in both directions and use water at the rate of 4 gals./sq.ft./min. The Palmer sweep uses about 1 gal./sq.ft./min. Surface washers effectively scour the sand at the start of the back wash operation. They reduce the amount of wash water that is required in the actual back wash operation.

## TIPS ON PROPER BACK WASHING OPERATION

Correct back washing procedure requires that the operator learn by experience the proper techniques that should be employed on every occasion. It is basic that a loss of head at which the filter should be washed be established or some reasonable period of time be chosen as an alternative. Adjustment should be made for winter and summer operation to assure required sand expansion. Wash water should be watched for evidence of media loss and for water spouts or uneven washing. It is essential that valves should be opened and closed slowly. This is particularly true of hydraulic valves. It must be remembered that pipe systems of filters are not designed for high pressures. Quick opening or closing of valves may cause water hammer with resultant high pressure development. Rapid opening of the filter effluent pipe valve may cause a shock which can open cracks or channels in the bed. Rapid opening of the wash water valve may do damage to the under-drains or it may form jets which will disturb the gravel layer. If the filter is air-bound, a quick opening of the wash water valves and the subsequent releasing of air may cause sand to carry

over the wash water troughs. It is obvious that one of the cardinal rules in the operation of a filter is that the valves should be opened and closed slowly. Equally important is that the filter should be back washed at the correct periods of time and with the proper amount of surface and back wash water.

#### DIFFICULTIES CAUSED BY IMPROPER BACK WASHING

There are many difficulties that are caused by improper back washing. One of the worst is that high rates may cause jets to break through weak areas of the gravel and sand and cause boils on the surface of the sand. The same high rate may also carry sand or anthrafil away with the wash water. If mud balls are present in the filter, excessive washing rates may create conditions that will cause mud balls to settle to the gravel and cause worse conditions to materialize. On the other hand, insufficient back washing can result in a dirty filter over a period of time that will result in air binding, loss of capacity and other undesirable conditions.

#### SUMMARY OF BACK WASHING

It is essential therefore that an operator know when, how and why the filter is back washed. The operation should be carried out properly if the plant is to continue to turn out a satisfactory product. There are many factors that enter into proper back washing procedure. It is quite true that there may be design deficiencies in a plant that will prevent proper back washing of a filter but often it is improper operation that is the cause.

#### MUD BALLS

One of the major troubles that occur in any filter is that which is caused by the creation of "mud balls." Their presence often indicates incomplete washing caused by insufficient velocity and bed expansion. "Mud balls" consist of deposited material retained in the bed. Such particles clump together forming masses known as "mud balls." This condition can gradually become worse if the back washing operation is not altered and improved. It is true that the invention of surface wash devices has improved back washing operation to the extent that "mud ball" conditions are not as common now as they were ten years ago.

#### EXCESSIVE "MUD BALL" CONDITIONS

In some instances mud balls will grow until they sink during the washing process and come to rest on the gravel bed. These mud layers are similar to mud balls only the material spreads out evenly over the bed after washing. This condition can be caused by ineffective back washing over a long period of time, a too low velocity wash water, washing time too short, troughs too high or too far apart or trying to operate the

filters at an excessive rate. Mud ball conditions that become layers can readily open cracks along the side walls and even in the filter bed proper. As a result, the filter will become useless as the water will readily find these cracks to the under-drains.

#### ELIMINATION OF MUD BALLS

Mud balls can be eliminated by careful operation provided they are observed soon enough. They can be minimized if on periodic occasions the filter is back washed for approximately twice the usual length of time. Examination of the upper sand at regular intervals is the best way to prevent the creation of mud balls. This material can be screened out manually by a #10 mesh screen, which will permit the sand to pass but will retain the mud material. Examination of the sand under a microscope will often show a coating that cannot be seen by the naked eye. In some filters where the washing has been ineffective over a period of time and particularly where there is no pre-chlorination of the water, this coating can cover all the upper sand of a filter and require its replacement. It is essential, therefore, that an operator be alert for the creation of "mud ball" conditions in the filter. Every effort should be made to not overload the filter, to back wash the unit at a suitable time, and to investigate sand conditions. This was at one time one of the major problems in filter operation but the assistance of the surface wash to the back wash operation has done much to minimize this condition.

#### SHIFTING OF GRAVEL

The purpose of gravel in the filter is two-fold (1) to support the sand and (2) to distribute the water from each orifice or the underdrainage system throughout the area of the filter. The junction of the sand or gravel in a filter bed has always a place where difficulty may materialize. There is always a certain amount of shifting of gravel but this can, on occasion, become a definite problem. Heavy back washing may force the gravel up and through the sand. There is no doubt that mud ball formation will hasten movement of the gravel. Poorly designed underdrainage systems or blocked orifices can be a contributory factor to this condition that is independent of the operation of the filters. The provision of underdrains of different designs such as Leopold blocks, Miller blocks, Wheeler bottoms, etc., has done much to eliminate this condition from filters.

#### TEST FOR VARIATION IN GRAVEL

An alert operator will test for variation in the gravel bed in the filter. Such a condition can be readily detected by a



probing rod during the back wash period. The inspection measures at any plant should include examination of each filter at least once a month and the sounding of the filter. In some cases, the mounding of gravel will be so severe that the media has to be entirely removed, the gravel and sand washed and then again re-installed in the filter. If the conditions that caused the mounding of the gravel are not corrected, the condition will again re-appear.

## AIR BINDING

Air binding is caused by the collection of air or gases in the lower parts of the bed and underdrain system. The head at a given elevation in a filter will become negative when the loss of head through the overlaying portion exceeds the static head at that point. Most filters operate under a partial vacuum at their lower levels toward the end of their run. It does not take long for the air to fill up the pore space or the underdrainage system when this takes place. As a result, the filter becomes "air bound" and loses capacity.

## CAUSE OF AIR BINDING

Air binding can be caused by operating a filter over an extended period of time in a dirty condition. As more and more suspended matter is entrapped in the filter it causes a consequent increase in the friction head and the creation of a negative head in the filter. The problem can also be accentuated if the level of the water over the filter is substantially lowered. Such a condition is favourable for the release of air. This release becomes faster when the water is warmed in passing through the filter. Therefore, air binding is a condition that is more prevalent in winter than in summer, although with faulty operation it can take place at any time during the year.

## PRECAUTIONS AGAINST AIR BINDING

There are precautions that should be taken against air binding. The main one is that the filter should not be overloaded and should be back washed at correct intervals and at recognized rates of back wash. The height of water above the sand should be maintained as high as possible. If air binding develops in a filter, the air can be expelled by floating it up with a short application of back wash and repeating this operation. While this bumping operation is a remedy, it can cause disturbance of the gravel layer and is not to be desired. Therefore in this case, prevention of the condition is far better than the cure.

## BREAK THROUGHS

There may be break throughs of suspended matter into the effluent at the start and the end of filter runs. In filters that are cracked there naturally can be break throughs throughout the run. The start-up break through is caused by floc within the sand that is not broken up during the washing process. This condition will be more prevalent if the media is coarse. The period of this break through may last for some time, on occasion, as long as 10 per cent of the total filter run.

At the end of the filter run, there can be filter break throughs particularly if the floc is weak. These can, on occasion, be anticipated by watching the relationship between the length of the filter run and the indication of the loss of head on the gauge. If the loss of head rises at a regular increasing rate throughout the run, it is generally an indication that no break through is occurring. On the other hand, if the loss of head increases less rapidly toward the end of the run or even drops, it is an indication that one can expect break throughs to exist.

## PRECAUTIONS THAT SHOULD BE OBSERVED IN OPERATION OF FILTER

It must be emphasized that operating a filter is somewhat similar to operating a motor car. If the filter is neglected, it will still function and run but with marked loss in efficiency. On occasion, due to various factors, it may even stop just like the motor car. On the other hand, if the basic rules are followed, a filter can operate for many years with little difficulty or loss in capacity. Some of these rules are listed as follows:

1. Provide proper pre-treatment of the water so that raw water conditioning becomes more important than the filtration operation.
2. Try to keep the water going on the filter uniform in quality. Endeavour to keep the turbidity of this water below 10 p.p.m.
3. Do not overload the filters over a long period of time. If raw water conditioning is adequate, a certain amount of overloading - up to 50% - is permissible. If raw water conditioning is inadequate or the filters are in poor shape, no overloading is permissible.
4. Do not try high rate filtration unless proper raw water conditioning and the hydraulic capacity of the plant will permit its use. In practically all old plants high rate filtration can not be used.
5. Carry out the back wash operation at regular intervals and according to established standards of loss of head,

sand expansion, rate of back wash and surface wash water and varying temperature of the water.

6. Watch for the creation of mud balls and mud layers in the filter. Test the sand or anthrafil on regular occasions to determine if this material is present.
7. Watch for shifting of the gravel in the filter and test on occasion with a probing rod during the back wash operation to determine if this condition is developing.
8. Avoid conditions that may cause air binding in a filter. This condition can be expected more in winter than in summer and special precautions should be exercised, when the water is cold.
9. Open and close all valves and particularly hydraulic valves slowly in order to avoid water hammer, high pressures in the piping and disturbances of the sand and gravel layers.
10. Give every attention to the maintenance of the valves and gauges that are essential to proper operation of the beds.
11. Do not keep water pressure on a hydraulic valve cylinder except when operating the valve. Hydraulic valve cylinders should be installed vertically for proper operation.
12. Check the rate controllers and loss of head gauges should be checked at frequent intervals to assure their continued good operation.
13. Watch the loss of head gauge for the evidence of a break through. If the loss of head drops toward the end of a filter run it is one indication of a break through.
14. If bacterial contamination is indicated in a filter, it is desirable that the filter be disinfected with a strong chlorine solution. This sterilization of a filter bed is standard practice in many plants.
15. Maintain the housekeeping of the filter plant to a high degree so that it not only is turning out good water but has the appearance in keeping with its efficiency.



SUSPENDED SOLIDS CONTACT UNITS IN ONTARIO

by

A. R. Townshend

Engineer in Charge of Plan Checking - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
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## SUSPENDED SOLIDS CONTACT UNITS IN ONTARIO

A. R. Townshend

ENGINEER IN CHARGE OF PLAN CHECKING - OWRC

### DESCRIPTION

The term "suspended solids contact unit" is used to describe a number of manufactured treatment devices which perform coagulation, solids-contact mixing and solids-water separation within a single basin.

The treating chemicals are precipitated in the raw water in contact with previously formed precipitates. The advantages claimed for this type of treatment are that chemical reactions are accomplished in a shorter time and higher flow rates are allowed by virtue of the larger floc particles formed. Solids are concentrated and removed from the units in the same quantities as they are precipitated.

Some units are equipped with backflush devices to facilitate keeping the sludge withdrawal lines free at all times and even withdrawal from all collection points.

A partial list of suspended solids contact unit manufacturers follows:

1. Accelerator - Infilco Incorporated;
2. Clariflow - Walker Process Equipment Incorporated;
3. Contraflo Upflow Clarifier - General Filter Company;
4. Hydro-Treator - Dorr-Oliver Incorporated;
5. Precipitator - The Permutit Company;
6. Reactivator - Graver Water Conditioning Company;
7. Reactor-Clarifier - The Eimco Corporation;
8. Solids Contact Reactor - Cochrane Corporation.

### SUSPENDED SOLIDS CONTACT UNITS SERVING MUNICIPAL WATER TREATMENT PLANTS IN ONTARIO

In Ontario, these units have been installed at municipal water works for softening and iron removal of well waters at

Cochrane; for simultaneous softening and coagulation at Dresden; and for coagulation of other surface supplies having both changing and unchanging raw water qualities. A list of suspended solids contact units at municipal water works is given in EXHIBIT I.

The first unit installed was an Accelerator in 1946 for softening and iron removal at Cochrane. A Precipitator was erected at Moose Factory in 1950 to supply the federal installations and townsite. The only Hydro-Treator was installed at Tilbury in 1955. The Union Water System - Essex County constructed by the OWRC in 1960 is equipped with a Reactivator.

The solids contact units are expected to operate satisfactorily over wide ranges of raw turbidity. Lake water turbidities ranging from 0 to 200 p.p.m. have been reported at Port Credit. River water turbidities ranging from 0 to 500 p.p.m. have been experienced at Streetsville and Thornbury.

The units usually reduce the turbidity to less than 10 p.p.m. and often less than 5 p.p.m. Higher values have been reported at Streetsville and Thornbury while treating raw waters in the 200-500 p.p.m. range.

The highest raw water colour concentration on record with the OWRC was obtained from the Beaver River at Thornbury. It was 125 p.p.m. High colour concentrations are also experienced at Moose Factory. The raw water colour concentration at Hawkesbury on the Ottawa River is in the 30 to 40 p.p.m. range. The raw water colour at the remaining plants is usually less than 10 p.p.m.

The effluent colour concentration is almost always less than 5 p.p.m.

#### RETENTION AND RISE RATES

The various manufacturers have adopted different designs in offering equipment for sale. Retention periods of 1 to  $1\frac{1}{2}$  hours are now generally suggested.

Operators in the U.S.A. have reported good softening and coagulation results with periods of  $1\frac{1}{2}$  to 2 hours.

Colder waters require longer contact time with the chemicals and slurry. Retention times between 2 and  $2\frac{1}{2}$  hours may be required for good coagulation of water supplies in Ontario during the winter months.

It has been found that shorter retention periods can usually be used for softening than for coagulation.

For rated capacities the retention times at plants in Ontario range from 0.8 to 2.5 hours.

The rise rate is usually expressed as GPM/ft<sup>2</sup> of surface area of settling zone. Rise rates not exceeding 1 U.S. GPM/ft<sup>2</sup> have been recommended by plant operators in the U.S.A. when clarifying low turbidity water at low temperature. For colour removal alone the rise rate should not exceed 0.75 U.S. GPM/ft<sup>2</sup>. Rise rates between 1.2 and 1.5 are recommended for lime softening.

For rated capacities the rise rates at plants in Ontario range from 0.71 to 2.7 U.S. GPM/ft<sup>2</sup>.

## OPERATION

Solids contact units are used continuously 365 days a year at 9 of the 14 municipal installations in Ontario.

The units at Cayuga and Thornbury on the Grand and Beaver rivers respectively are not used during the cold winter months.

At Port Credit the Accelerator is used only when the raw water turbidity exceeds the 10 to 20 p.p.m. range. It was used on 63 days in 1960.

The Accelerator is used very intermittently at Port Dover. The unit was used for about six days in 1960.

## CHEMICALS AND DOSAGES

### Coagulant

Aluminum sulphate (alum) is used at all of the solids contact coagulation installations in Ontario. Alum dosages between 7 p.p.m. (0.5 gpg) and 50 p.p.m. (3.5 gpg) have been recorded at the Ontario plants. (14.1 p.p.m. = 1 gpg).

The coagulant dosage should be as low as possible and still obtain good results. Too much coagulant may make the floc too light for fast settling. As the raw water turbidity or colour increases the amount of coagulant should be increased. If the character of the suspended matter changes, more or less coagulant may be needed.

### Coagulant Aids

The floc formed by the coagulant alone may not settle quickly. Where the water is clear and cold and the floc formed is fine and light in density or where colour and organic matter

are to be removed coagulant aids may be added to weigh the floc or aid in neutralizing static charges to form larger floc particles.

Activated silica is used at Lindsay, Hawkesbury and Oakville to weigh the floc. Dosages between 2.2 and 5.5 p.p.m. have been used.

Clay may be added to raw water that is low in natural turbidity. It substitutes for natural suspended matter as well as having some coagulating properties of its own. Clay is available at the Union Water System - Essex County to treat the raw Lake Erie water.

Crushed limestone is used at Streetsville to weigh fine suspended silt particles when the raw water turbidity exceeds 25 p.p.m. Dosages between 5 and 50 p.p.m. have been recorded.

Hagans No. 18 coagulant aid has been tested at Lindsay on a trial basis using about 2.1 p.p.m.

Other commercial compounds are available for this purpose. Coagulant aids may be used with the purpose of reducing the amount of coagulant required. The best amount of coagulant aid to feed is the least amount that will give good results.

### Alkali

For optimum coagulation the pH must be carefully controlled. Changes in the amount of alkalinity and free carbon dioxide in the raw water are seasonal with most surface supplies. If the pH of the water is too low for good coagulation an alkali is required.

Lime is used at Cayuga and Hawkesbury for this purpose. Dosages between 20 and 28 p.p.m. have been recorded at these plants.

### Softening

Where partial softening is required lime and soda ash are used as reagents.

Lime is used at Dresden to soften the Sydenham River water and at Cochrane to soften well water. The dosages used vary between 115 and 322 p.p.m. at Dresden and 224 to 400 p.p.m. at Cochrane.

The use of soda ash at Dresden has been discontinued.

Coagulants and coagulant aids may also be used in the lime softening process to remove suspended matter or colour present in surface supplies and to coagulate the fine calcium carbonate precipitates.

Alum is used at both Dresden and Cochrane at dosages between 18 to 72 p.p.m. and 7.4 to 14 p.p.m. respectively. Sodium aluminate was tested at both of these plants on an experimental basis but the chemical did not prove to be more economical than alum.

#### POINT OF CHEMICAL FEED AND ORDER OF CHEMICAL USE

The best point of application varies from plant to plant. This can usually be determined by jar tests.

Some operators find that best performance is obtained when the old sludge contacts incoming water and chemical immediately after entrance into the suspended solids contact unit. If a chemical is added to the water before it reaches the basin it may form new colloidal precipitates which do not adhere to the old sludge nuclei.

At one Hydro-treator installation in the U.S.A. addition of lime for softening directly into the basin caused the sludge to cement and stop the distributor arms. This was eliminated by adding the lime to the raw water line ahead of the unit.

Experience has shown that the order of adding coagulants and coagulant aids can make a significant difference in the results achieved. This should be determined at each plant by experiment and/or by jar tests.

# E X H I B I T I

## SUSPENDED SOLIDS CONTACT UNITS SERVING MUNICIPAL WATER WORKS IN ONTARIO

YEAR INSTALLED	MUNICIPALITY	TYPE	RATED CAPACITY U.S. GPM	SOURCE	TREATMENT PROVIDED	PERIOD OF OPERATION
1946	Cochrane	Accelator	840	Wells	Softening & iron re- moval	Continuous
1949	Port Credit	Accelator	1400	Lake Ontario	Coagula- tion	Intermittent 63 days in 1960
1950	Moose Factory	Precipitator	120	Moose River	Coagula- tion	Continuous
1952	Hawkesbury	Accelator	2800	Ottawa River	Coagula- tion	Continuous
1954	Port Dover	Accelator	700	Lake Erie	Coagula- tion	Very Inter- mittent - 6 days in 1960
1955	Tilbury	Hydro-Treator	2000	Lake St. Clair	Coagula- tion	Continuous
1956	Cayuga	Accelator	200	Grand River	Coagula- tion	March to December ±
	Oakville	Accelator	10,060	Lake Ontario	Coagula- tion	Continuous
1958	Dresden	Accelator	480	Sydenham River	Coagula- tion & soft- ening	Continuous

CONT'D

CONT'D

E X H I B I T I

SUSPENDED SOLIDS CONTACT UNITS SERVING  
MUNICIPAL WATER WORKS IN ONTARIO

YEAR INSTALLED	MUNICIPALITY	TYPE	RATED CAPACITY U.S. GPM	SOURCE	TREATMENT PROVIDED	PERIOD OF OPERATION
	Lindsay	Accelator	2100	Scugog River	Coagula- tion	Continuous
	Streetsville	Accelator	685	Credit River	Coagula- tion	Continuous
	Thornbury	Accelator	540	Beaver River	Coagula- tion	March to December ±
1960	Riverside	Accelator	3000	Detroit River	Coagula- tion	Continuous
	Union Water System-Essex C.	Reactivator	6600	Lake Erie	Coagula- tion	Continuous
1961	Pickering Twp.	Reactivator	1045	Lake Ontario	Coagula- tion	Under Construction



## NORMAL OPERATION

Each equipment supplier has his own set of operating instructions. The details vary because of the differences in equipment and design principles used.

It is hoped that the following general procedures may be applied to all municipal installations in Ontario.

## INITIAL OPERATION

All water lines should be flushed out to remove mud and scale. Any grease or oil should be removed from the interior faces of the equipment. The drain line and sludge removal system should also be flushed clear.

After optimum chemical dosages have been determined from the raw water analyses, the chemical feed systems should be charged and placed in operation while the unit is filling.

The unit should be filled using a rate of approximately  $1/2$  to  $2/3$  of rated capacity. When the water reaches the effluent launders they should be checked for level.

The use of a low agitator speed is recommended during the start-up period at coagulation plants. Higher speeds may be necessary at softening plants.

During the initial start-up period the effluent should be discharged to waste. This is to prevent carry-over of excessive turbidity to the filters or to the distribution system, until such a time that satisfactory treatment has been established.

Continuous water flow at the above rates and adjusted chemical feed rates should be maintained until the desired sludge concentration is reached. Once a slurry is formed normal rates and chemical dosages may be used.

De-sludging should not be started until a full sludge blanket has been formed. It may take several days to build up a satisfactory blanket depending on the water characteristics. The time required may be shortened by feeding large amounts of chemicals or clay but best results will not be obtained until the types of solids and their density reach an equilibrium value with proper amounts of chemicals fed.

During the start-up period the sludge withdrawal line should be back-flushed a minimum of once or twice a day for up to 20 seconds to maintain it free of solids. The rate of back-flush should be such that the sludge is not raised to the surface.

## AGITATOR SPEED

During the normal operation the agitator should be run as fast as possible without causing disturbance of the sludge blanket. Agitation must be great enough to thoroughly mix the slurry, raw water and chemicals and to keep them in suspension.

Some operators feel that proper agitation to obtain maximum contact with the old sludge particles is more important than the concentration of the solids.

With low turbidity waters the best operation is often obtained with the agitator speed reduced. Generally, when treating cold water the agitator speed should be increased.

## SLURRY STRENGTH

The actual strength of slurry to be carried will vary with load, temperature, characteristics of the precipitate and other factors. After sampling over a period of good operation, the operator should learn the proper slurry strength for his particular plant.

The concentration of solids is measured by a volume settling test. A 100 ml sample of the slurry is collected in a 100 ml graduated cylinder and allowed to settle. The settling time used varies among the manufacturers from 5 to 20 minutes. The volume occupied at the end of the settling period is the strength in percent solids.

Slurry strength may be determined at more than one point in the tank. At Reactivator plants sludge is sampled at the lower and upper draft tubes and allowed to settle for 10 minutes. The manufacturer recommends that the two concentrations should not differ from each other by more than 5%. At the Union Water System-Essex County, a concentration of 20%  $\pm$  is carried.

It is therefore difficult to compare slurry concentrations from plant to plant unless they are of the same type. At the Accelerator plants in Ontario slurry strengths from 5% to 20% based on a 5 minute settling test are carried.

Although a slurry is necessary for coagulation its exact concentration within allowable limits is not too critical.

Softening seems to improve as the slurry concentration increases. Therefore the highest concentration that will not result in floc carry over should be used.

## SLUDGE REMOVAL

The weight of solids discharged from the sludge hoppers or concentrators must equal the weight of solids formed.

The amount of waste water is very similar to that of other types of treatment. The amount wasted ranges from 1 to 5% of the total treated water for coagulation units and from 0.5 to 4% for softening units. The amount of blow-down may also be expressed as from 0.2 to 1.0% of inlet water for each 100 p.p.m. removed.

The concentration of solids in the blow-off of the sludge concentrator is usually from 80 to 95%.

The volume of sludge to be wasted can be calculated from the weight of chemicals added; total weight of impurities removed from the raw water; and the density of the sludge. Once this is known the automatic blow-off valves can be set to discharge at frequent intervals during the day.

For those units equipped with back-flushing devices each back-flush may last from 5 to 20 seconds but will vary with local conditions. The sludge should be examined during blow-off. If there is dense sludge followed by very thin sludge the back-flush time should be lengthened. If the sludge is thin for the entire time the back-flush is too long.

## BOTTOM DRAIN

The bottom drain connection is used to remove accumulations of heavy sludge or sand which are too heavy to be kept in circulation.

The drain should be opened regularly as found necessary (perhaps weekly) by experience. The agitator should be run when the drain is open. The valve should be opened full and held open until heavy sludge or large particles no longer appear. An excessive amount should not be discharged as this decreases the solids in circulation.

It is considered good practice to drain and clean these units once every six months. This should be done religiously at softening plants. Lime or lime-soda ash softening reactions may create a scaling condition. The scale can build up on the mechanical moving parts and the steel partitions. This added weight may damage the drive mechanisms and/or supporting structures unless the scale is removed regularly.

## ADJUSTING CHEMICAL DOSAGES

Too high a coagulant dosage decreases the density of the sludge. This may cause the sludge blanket to rise beyond the maximum desirable limit, possibly causing a carry over of sludge.

Since the action of the coagulant is affected by the pH value of water it is necessary to control the pH within a certain range. Colour is most effectively removed at low pH. Where turbidity removal alone is desired the pH range can be wider.

If the slurry concentration decreases and the level rises it is usually due to incorrect chemical treatment or faulty coagulation. A temporary decrease in mixing speed may be necessary until proper dosages are determined. If the chemical tests indicate that treatment should be changed, the base charges or feed rates should be increased or decreased from 2 to 5% at a time.

## OPERATING DIFFICULTIES

### RATE OF FLOW

All sudden increases in rate of flow should be avoided. Increases in rate of flow should be accomplished slowly to prevent upsetting the sludge blanket.

The units should not be operated at too low a rate. Sizeable surges at half design flow are more of a problem than at design flow. The slurry is usually thinner at lower rates and more difficult to keep in suspension.

In operating at a varying rate of flow, it is desirable to carry the sludge blanket at a lower level in order to ensure a greater margin of safety. If the rate of flow is constant, the sludge level may be carried higher.

Some operators in the U.S.A. have reported that as long as the chemical feed and waste sludge controls are changed accordingly the changes in rate of flow from 50 to 130% of rated capacity do not upset the units. However in this study no attempt was made to compare the rise rates at these plants with those where such changes caused upsets.

### CHANGES IN RAW WATER QUALITY

Sudden changes in the physical and chemical qualities of the raw water can be disturbing unless detected soon afterwards.

Under such conditions chemical control tests should be conducted every hour or two hours. It may however take from 3 to 4 hours for the changed chemical dosages to establish equilibrium.

#### GASES IN THE RAW WATER

In softening plants treating well supplies sufficient aeration should be provided ahead of the suspended solids contact unit to drive off dissolved gases in the raw water. Otherwise the gases will tend to raise and float the slurry.

When present in surface supplies algae should be controlled by the use of micro strainers and/or prechlorination to prevent growth in the solids contact unit, with the release of carbon dioxide gas during the respiration cycle.

Suspended air may be introduced in pump suction piping and pump glands in both the raw water supply and chemical feed systems.

#### ORGANIC SOLIDS IN THE SLURRY

A sludge blanket loaded with decomposing organic material is a breeding place for taste and odour. The blanket may deteriorate causing heavy carry over into the effluent. In such cases sufficient pre-chlorination may be required to give a free chlorine residual.

If heavy chlorination still results in a pronounced taste and odour it becomes necessary to provide activated carbon treatment. For example, activated carbon is fed directly into the Accelerator at Streetsville during periods of the year when the Credit River is susceptible to taste and odour conditions.

#### TEMPERATURE CHANGES AND SUNLIGHT

Temperature changes of the raw water source are usually not abrupt enough to disturb the slurry in the solids contact units. Temperature changes in excess of  $2^{\circ}\text{F}$  per hour may cause difficulty.

Local temperature changes due to the sun shining on open tanks do cause variation of the slurry level. One operator in the U.S.A. reported that the level appears to drop at night and on cloudy days and to rise again when sunlight returns. Similar observations have been made at the Union Water System-Essex County treatment plant.

## CHEMICAL FEED INTERRUPTIONS

For best results there should be no interruptions in chemical feeding. Some operators in the U.S.A. reported no serious effect upon water quality for short interruptions up to 30 minutes while others reported a noticeable carry over of alum floc within 10 minutes. Clay and lime feed interruptions did not seem to have such a marked effect.

At softening plants the hardness increased; the size of particles in the slurry decreased and the effluent turbidity increased when lime and alum dosages were too low. Variations in soda ash feed appeared to have less adverse effect.

## OPERATING INSTRUCTIONS

### MAINTAINING THE SLURRY LEVEL

The top of the slurry blanket is kept at the best operating level by varying the sludge blowoff. Assuming that the slurry strength remains constant, if the blanket level goes up, the blowoff should be increased, and if the level drops, the blowoff should be reduced.

One of the factors listed in the table below may raise or lower the blanket level. It is not desirable to change the blowoff rate if the condition is only temporary. By sampling the slurry strength and using the table as a guide, the operator can determine when to change the blowoff rate and when to leave it alone.

T A B L E

Factors Increasing Slurry Strength or Lowering Blanket Level	Factors Decreasing Slurry Strength or Raising Blanket Level
Lower rate	Higher rate
Higher hardness of Inlet Water (lime softening)	Lower Hardness of Inlet Water (Lime softening)
Higher Inlet Water Turbidity. Heavier Inlet Water Turbidity.	Lower Inlet Water Turbidity. Finer or Lighter Inlet Water Turbidity.
Higher Inlet Water Temperature	Lower Inlet Water Temperature
Use of Coagulant Aids	Increased amount of coagulant



# CHECK LIST OF OPERATING DIFFICULTIES

Symptoms	Causes	Check Points
I. High turbidity Cloudy appearance	1. Inadequate chemical treatment	a. check treated water analysis b. check chemical feeders c. check chemical treatment requirements by jar tests.
	2. Insufficient sludge in circulation	a. check agitator speed b. check sludge conc. c. check blowoff devices for proper operation.
II. Continuous Floc carryover with low sludge level in settling zone.	1. Inadequate chemical treatment.	a. check treated water analysis b. check chemical feeders c. check chemical treatment requirements by jar tests.
	2. Excessive agitator speed	a. check agitator speed
	3. Air entrainment	a. check raw water piping for air introduction. b. check raw water pumps for air leakage through glands. c. check chemical pumps for air leakage through glands. d. check chemical feed system for air introduced by vortexing.
III. Intermittent or periodic floc carry over with low sludge level in settling zone.	1. Variable raw water composition.	a. check raw water analysis during difficult period. b. check treated water analysis during difficult period. c. run jar tests to determine treatment requirements during difficult period.
	2. Erratic feeder operation	a. check chemical feed controls. b. check chemical feeders for bridging.

Symptoms	Causes	Check Points
		<ul style="list-style-type: none"> <li>c. check chemical feeder calibration</li> <li>d. check chemical pump delivery.</li> </ul>
	3. Variable raw water temperature	<ul style="list-style-type: none"> <li>a. continuously check raw water temperature.</li> <li>b. run jar tests to find treatment to give heavier floc.</li> </ul>
	4. Air entrainment	<ul style="list-style-type: none"> <li>a. check raw water piping for air introduction.</li> <li>b. check raw water pumps for air leakage through glands.</li> <li>c. check chemical pumps for air leakage through glands.</li> <li>d. check chemical feed system for air introduction by vortexing.</li> </ul>
	5. Repeated flow surging.	<ul style="list-style-type: none"> <li>a. check inlet control device for proper operation.</li> <li>b. check level controller for proper operation.</li> <li>c. check raw water pressure for variations.</li> </ul>
	6. Variable sludge concentration	<ul style="list-style-type: none"> <li>a. check sludge concentration</li> <li>b. check blowoff device for proper operation</li> </ul>
	7. Excessive backflush	<ul style="list-style-type: none"> <li>a. check backflush water pressure.</li> <li>b. check backflush timer setting.</li> </ul>
<hr/>		
IV. High sludge level in settling zone	1. Excessive quantities of sludge in unit	<ul style="list-style-type: none"> <li>a. check blowoff device</li> <li>b. check sludge concentration</li> <li>c. check agitator speed</li> <li>d. where applicable, check Scraper operation.</li> </ul>



Symptoms	Causes	Check Points
	2. Light Sludge	<ul style="list-style-type: none"> <li>a. check blowoff sludge conc.</li> <li>b. check treated water analysis.</li> <li>c. check raw water analysis</li> <li>d. check chemical feeder operation</li> <li>e. check for settling rate in jar tests.</li> <li>f. check for septic sludge-odour, colour, pH.</li> <li>g. check agitator speed.</li> </ul>

CHEMICAL ANALYSIS OF WATER

by

C. E. Simpson

Supervisor - Chem. Labs. - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
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## CHEMICAL ANALYSIS OF WATER

C. E. Simpson

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Since nearly all of the control analyses for waterworks have been touched on in previous lectures, the Chlorine Demand Test was chosen to be examined here in detail, with a subsequent demonstration both of this test and of the Threshold Odour Test.

The chlorine demand of a water is the amount of chlorine that the water uses up in a given time; the difference between the chlorine added and the chlorine residual.

'Chlorine Demand' is often spoken of as if a single chlorine demand value existed for any given water. This is understandable because of the widespread application of marginal chlorination. When someone says "the chlorine demand of our water is (for instance) 0.9 ppm", the listener usually understands that the speaker means, in addition, "to produce a 0.2 to 0.3 ppm chlorine residual after 15 minutes contact." In fact, a raw water may have any of a wide range of chlorine demand values, depending on how completely the chlorine has been allowed to, or forced to, react with those materials in the water which use up, or 'demand' chlorine. Thus, when comparing chlorine demands, or when requesting a test at another laboratory, specify exactly the conditions of test, or of plant practice which apply. These define the conditions which result in the single chlorine demand value reported. e.g. "Using (marginal, super, or break-point) chlorination to produce a (free or combined) residual of \_\_\_ppm, after \_\_\_mins. contact at a temperature of \_\_\_° (C or F) and a pH of \_\_\_ the chlorine demand of this sample of water is \_\_\_ppm."

Among these conditions which influence chlorination, hence chlorine demand, there are two that the plant operator (or at least the plant designer) can control at will: Contact Time and Chlorine Dosage. Two other factors are usually impractical to manipulate because of cost, but their influence must be kept in mind and if necessary, compensated for: Temperature and pH. One final factor is unalterable (but not unaltering). This is Raw Water Quality.

Unless a variety of alternate sources is available the quality of the raw water is the basic factor with which the operator can do nothing but cope, by manipulation of the other controllable factors. Before we examine these, a review of the basic chemical reactions of chlorine is in order. For this purpose, those compounds containing "available chlorine" can be considered to react similarly to elemental chlorine gas, in that they produce the same effects; bleaching and disinfection, have a similar odor, are similarly poisonous and corrosive etc. These properties are all dependent basically, on the "oxidizing power" of chlorine -- its tendency to react like oxygen. (There are many oxidizing chemicals: Fluorine, Bromine, Iodine; Sulphuric, Nitric and Perchloric Acids, etc.)

For instance, hydrogen and oxygen gas mixtures burn, explosively under the proper conditions to form water:



(Note: For sound reasons, elemental gases are considered to exist as two atoms bound together. Thus,  $\text{H}_2$  instead of  $\text{H}$ ,  $\text{O}_2$  instead of  $\text{O}$ ,  $\text{Cl}_2$ ,  $\text{I}_2$  etc. Unfortunately, this complicates the writing of chemical equations.)

Similarly hydrogen and chlorine gas mixtures burn, explosively under the proper conditions to form hydrochloric acid.



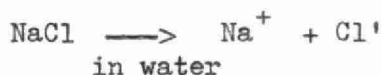
Continuing, sodium and other metals are oxidized by oxygen to form oxides.



Sodium and other metals including iron are oxidized by chlorine to form chlorides.



Note: In this reaction corrosive, poisonous sodium metal and corrosive poisonous chlorine gas combine to form the relatively non-corrosive, non-poisonous salt sodium chloride, illustrating the profound changes in chemical properties which are produced during chemical reactions. Further, if sodium chloride is dissolved in water the salt ionizes to form positive sodium and negative chloride ions.



This overall conversion from free chlorine  $\text{Cl}_2$  to the chloride ion  $\text{Cl}^-$  is the characteristic 'oxidizing' reaction of chlorine in water. The fundamental change involved is a transfer of electrons, those negatively charged particles found inside the atom. Each free chlorine atom has a deficiency of one electron, and reacts with other chemical atoms or molecules which can supply an electron.

Thus as chlorine in water exerts and loses its oxidizing power, it is picking up electrons from all possible compounds and being transformed into negatively charged chloride ions  $\text{Cl}^-$ .

There are a wide variety of chemical compounds which may be found in water which chlorine can oxidize by robbing them of electrons. These chemicals by losing negative electrons become more positively charged (like  $\text{Na}^+$ ) to balance the negative  $\text{Cl}^-$  formed. For many pure chemicals the reaction with chlorine is well understood, and chemical equations have been developed to illustrate the reactions as they occur in water treatment. The value of these equations is not only that they give a picture of what is happening in a type of 'chemical shorthand' but also that they show the amounts or ratios in which the chemicals combine. The following are a series of examples, simplified in some cases. The formation of a more positive charge is indicated by underlines.

## HYDROGEN SULPHIDE REMOVAL

Chlorine quickly reacts with hydrogen sulfide ( $H_2S$ ), converting it to sulfur (S) or to sulfate ( $SO_4$ ), depending upon the amount of chlorine applied.

1. Conversion of  $H_2S$  to S by chlorination:



pH--optimum pH 9.0, range pH 5-9

Temperature--not an appreciable factor

Time--rapid at pH 9.0 slower as pH decreases

Chlorine required--2.1 ppm for each 1 ppm  $H_2S$

The sulfur formed is precipitated and can be removed by filtration. (The presence of free sulfur is indicated by a cloudiness in the water and demonstrates an absence of free available chlorine.)

2. Conversion of  $H_2S$  to sulfates ( $SO_4$ )<sup>++</sup> or ( $S^{+++++}O_4$ )<sup>++</sup>



pH--optimum pH 5.0, range pH 6.5-9

Temperature--not an appreciable factor

Time--rapid at pH 5.0, slower as pH increases to 9.

Chlorine required--8.5 ppm for each 1 ppm  $H_2S$

The sulfates formed are soluble and do not produce a haze in the water. The presence of free available residuals will indicate that all of the sulfides have been converted to sulfates.

## IRON REMOVAL

Chlorine will oxidize ferrous iron according to the equation:



The soluble ferrous bicarbonate,  $Fe(HCO_3)_2$ , is oxidized by chlorine to the insoluble ferric hydroxide,  $Fe(OH)_3$ , which can be settled out or removed by filtration.

pH--optimum pH 7.0 and above, range pH 4-10

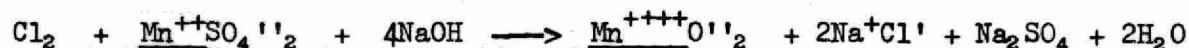
Temperature--the reactions are relatively slow in cold water

Time--maximum 1 hour, faster at optimum pH

Chlorine required--0.64 ppm for each part of iron as Fe

#### MANGANESE REMOVAL

Chlorine will oxidize manganous manganese to insoluble manganese dioxide ( $\text{MnO}_2$ ):



The manganese dioxide produced may be removed by filtration. The dark deposits of manganese dioxide, which plate-out on the sand grains, act as a catalyst and make possible the complete extraction of manganese from water.

pH--optimum pH 7.0, range pH 7-10

Temperature--not an appreciable factor

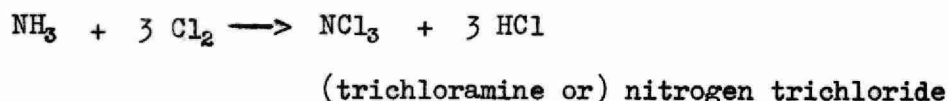
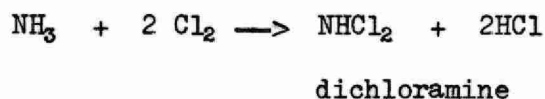
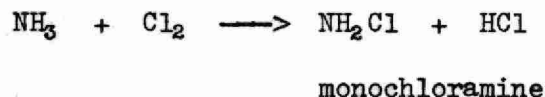
Time--2 to 3 hours at pH 7.0, less as pH and chlorine residuals are increased.

Chlorine required--1.3 ppm for each part of manganese as Mn, exclusive of the requirements for iron, ammonia, hydrogen sulfide, etc. The chlorine must be in the form of free available chlorine.

Alkalinity--reaction requires 3.4 ppm alkalinity as calcium carbonate ( $\text{CaCO}_3$ ) for each part of manganese as Mn.

#### CHLORAMINE FORMATION

Chlorine reacts with ammonia to form a series of chloramines depending on the ratio of chlorine to ammonia used and on the pH.



pH--above pH 8 only monochloramines are formed  
between pH 5 to 8 both mono- and dichloramines are present  
As the pH decreases the latter predominates  
below pH 4 only trichloramines are formed

Thus, at the pH of average waters (pH 7 to 8), and ratios of ammonia nitrogen to chlorine of 1:3 or 1:4, the 'combined' chlorine is present both as monochloramine and dichloramine.

#### BREAK POINT CHLORINATION

When the chlorine ratio is increased to 10 of chlorine to 1 of ammonia nitrogen, or higher, a further reaction occurs whose equation is not yet understood. The ammonia is converted to products mainly nitrogen gas ( $N_2$ ), possibly some nitrous oxide ( $N_2O$ ), nitrogen trichloride ( $NCl_3$ ), and of course the chloride ion  $Cl^-$  is formed as hydrochloric acid  $H^+Cl^-$ .

Optimum pH- 7.5 Range 6.5 to 8.5

Dosage ratio of chlorine to ammonia N:

10:1 for ammonia nitrogen in water  
25:1 for highly polluted waters  
15:1 average

#### OXIDIZABLE ORGANIC MATERIAL

In surface waters especially, many of the objectionable materials which react with chlorine have as yet, been impossible to investigate as pure compounds. These include a wide variety of organic compounds, both natural and pollutant, which may total only a few ppm. Individual components may be present in only parts per billion and yet have distinctly objectionable tastes and odours. Although much research effort is being devoted to carbon adsorption studies in efforts to identify these materials and measure their concentrations in major surface waters, as yet there has been no major breakthrough. As an indication of the difficulty of the techniques involved, each sample examined in these studies is presently costing about \$40.00, mostly for laboratory labour.

So the practical approach is still the most rewarding in many of these cases. An 'unknown' water should be checked first for the presence of obvious substances which exert chlorine demands. Then a series of chlorine demands is run, varying the control factors to determine which combination of these is most effective in yielding the result desired; disinfection, taste and odour removal etc. The effect of variations of the two (usually) non-controllable factors, Temperature and pH should be considered.

## TEMPERATURE

A general rule in chemistry is that reactions occur more rapidly with an increase in temperature. e.g. BOD test uses up oxygen 5% more rapidly for each 1°C rise in temperature. This is compounded so that 2°C rise exerts an increase of 5% of 105% etc.

An unreliable general rule is sometimes quoted, 'for each 10°C rise the rate of reaction is doubled', but in the orthotolidine test for instance, a combined residual chlorine maximum color is reached:

in 6 mins. at 0°C  
3 mins. at 20°C  
7½ mins. at 25°C

or requires a 20°C rise to double the rate

Chlorination reactions are similarly more rapid at higher temperatures. However, no plant is going to the expense of heating the water to improve chlorination. There are more effective ways of achieving this without thwarting the consumers preference for water as cold as possible. Temperature effects cannot be ignored, though. The cyclic seasonal fluctuations in water temperature will exert a noticeable effect on the chlorine demand in surface waters, in summer inducing more rapid reactions, therefore, a higher demand within the same period of contact. Well supplies may show a lag in the arrival of maximum and minimum temperatures.

## pH

It is uncommon to find reactions which are not influenced by pH. As was noted in previous lectures a seemingly small pH change corresponds, in fact, to enormous variations in the hydrogen ion ( $H^+$ ) concentration. A water at pH 4 has 1000 times the  $H^+$  content of a water at pH 7 which in turn has 1000 times the  $H^+$  content of a water of pH 10.

In chlorination, pH is often an influential factor, as noted for the equations quoted above. In the killing rate for bacteria a decrease in the efficiency of disinfection is shown for increasing pH.

pH	Minutes required for disinfection by 0.5 ppm $Cl_2$
4.5	20
6.8	30
8.5	60



Although pH adjustment is seldom used to control chlorination, pH disturbances may be produced by the addition of the chlorine compounds themselves (hypochlorites) or by other treatment practices, alum dosages etc. The resulting pH is not always as constant as might be desired and soft waters especially, should be watched for any influence pH variations may have on the efficiency of chlorination.

Finally we come to those factors involved in Chlorine Demand over which the operator has control: Time and Dosage.

## TIME

One of the reasons time has an influence on reactions is that mixing cannot be obtained instantaneously. In order to promote a complete reaction between the minute concentrations of chlorine (1-10ppm) with the equally sparse concentration (or population) of oxidizable material, the individual atoms must be helped to find one another. Thorough, intimate mixing is essential.

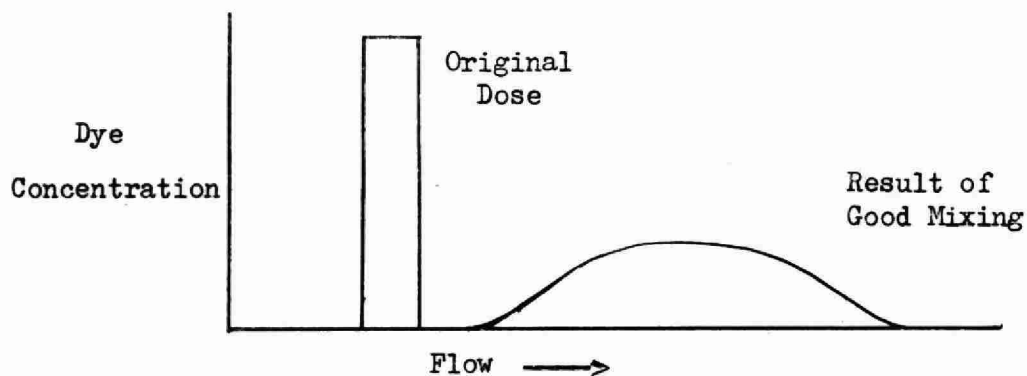
In the bench test this is relatively simple to achieve by stirring. In plant practice it is common to make use of those mixing operations used for other treatment operations; sedimentation and clear well retention etc. or to make use of turbulent flow in pipes, especially as induced by sharp changes of direction, right angled elbows etc.

Under operating conditions it is difficult to check for complete mixing. The production of a stable residual free from random fluctuation, soon after chlorine addition is the best assurance. Under emergency conditions the addition of a dye in the same manner as the chlorine may be used to check on mixing. If the dyed water can be wasted, a dye check is possible without consumer complaints.

Adding dye continuously, a gradual stabilization of the dye content should be observed. Once this has been obtained there should be no perceptible variations and especially no gaps in the presence of color. These indicate inadequate mixing.

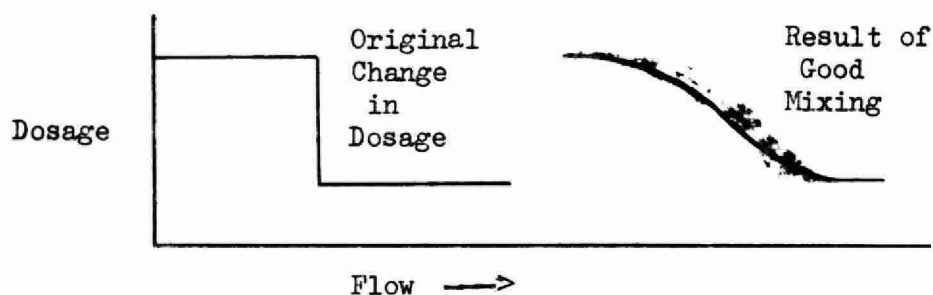
Another way to check mixing of chlorine is to utilize any abrupt change in the chlorine dosage, and observe the resultant changes in the chlorine residual at the point where mixing is expected to be complete. There should be a smooth change in concentration.

For instance, if a slug of 1 gallon of dye at 1 ppm were added it would not persist at that volume and concentration, but would be diluted by mixture with water which had been flowing both ahead of and behind it in the pipe. From turbulent pipe flow, an appreciable degree of mixture would be expected; by passage through a retention tank, clear well etc. good mixing would distribute the dye through a quantity of water equal to a number of times the volume of the tank.



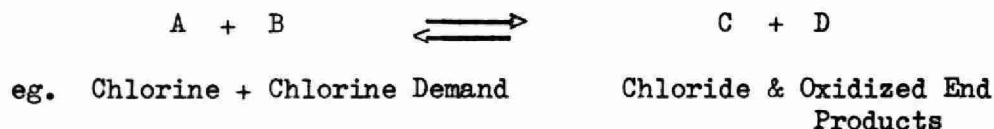
The sharp graph represents conditions in a bench test. In plant practise the effect is extended and 'blurred'. This is one factor in the 'vague' results which are often noted in plant practise - in fact a given sample drawn from the pipes after 15 minutes flow, may contain some water which has had both as little as 5 or 10 minutes contact and as much as 30 minutes.

Similarly using an abrupt change in concentration as a guide, a smooth change indicates good mixing.



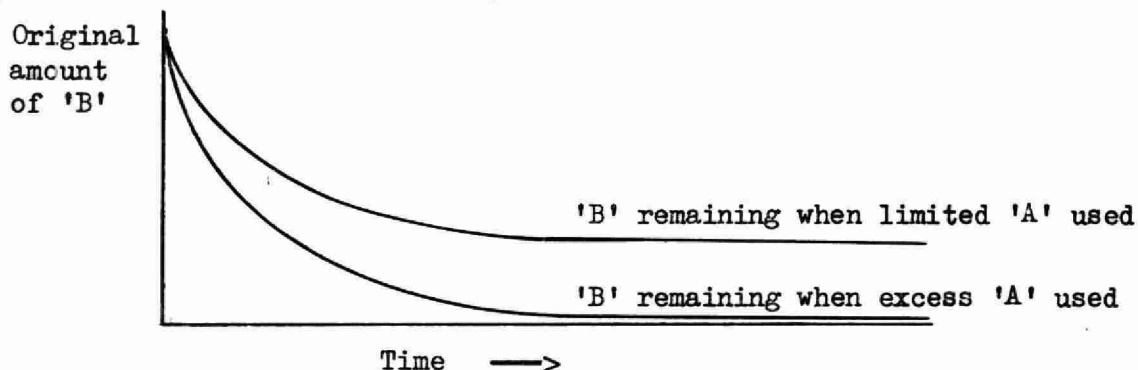
In addition to the delay in reaction occasioned by the mixing period, there is often an appreciable delay due to 'rate of reaction'.

Chemical reactions, the exchange of electrons etc. take perceptible time. Inorganic reactions (those between mineral materials) are in general very rapid, often achieving completion in a fraction of a second. For organic reactions the rates of reaction are slower. Some take days to reach equilibrium at room temperature. Another characteristic of organic reactions is that they slow down and stop (at equilibrium) before all the raw materials are completely used up. This is indicated by reverse arrows in equations.



No further reaction may occur even though appreciable quantities of A + B are still present. To force the reaction to produce as much C + D from say B, A can be increased to such a degree that it forces nearly all B to react. Note the effect of increased  $\text{Cl}_2$  dosage on the sulphide and ammonia reaction equations quoted previously. In these cases it even alters the products formed.

The combined result of the mixing and rate of reaction time lags gives a characteristic time graph.



The reaction gets slower and slower as the concentration of B (and of A) decrease. Using excess A (chlorine for example) forces the reaction to go more quickly, and reduces the amount of B (chlorine demand) remaining as yet unreacted.

#### CHLORINE DOSAGE

The effect of the remaining variable, chlorine dosage, which is most readily controlled by the operator, is best examined through the preparation of a chlorine demand graph, on which chlorine residual readings are plotted against chlorine dosages. By obtaining complete curves at various pH's, various temperatures or various contact periods the effect of these factors can be visualized. The data from which the curves are plotted is obtained by measuring, at the end of a chosen contact period, the residual chlorine in a series of identical samples which have been dosed with increasing concentrations of chlorine. Each sample in a set must be at the same pH and temperature and these values and the contact time should be recorded on the graph.

A reference line on the graph can be drawn to represent a zero demand curve i.e. the result if the residual could be measured immediately after the chlorine were added, before any reaction had occurred. This line shows a 1 to 1 slope; for each ppm of chlorine added there would be a full 1 ppm increase in the residual. Since the residual actually measured following the chosen period of contact will be less than the amount added, the vertical 'spread' between the reference line and the 'residual curve' shows the amount used up; the chlorine demand at any given dosage. As long as the 'residual curve' angles away from the reference curve the chlorine demand is being increased. If the 'residual curve' becomes parallel to the reference line, it is showing a 1 to 1 slope, hence the demand is not being increased further.

If the curve is obtained for longer and longer periods of contact (say 15 mins., 1 hour, 6 hours, 24 hours, etc.) it is often found that lower and lower curves are obtained, indicating more complete satisfaction of the demand.

For low demand waters (those containing little oxidizable material) the chlorine demand curve only shows a slight drop from the theoretical line, and becomes parallel to it at low chlorine dosages.

For waters containing larger quantities of oxidizable material the chlorine demand curve usually shows continually increasing demands until a much higher chlorine dosage is reached. Thus the effect of increased chlorine dosage in driving the reaction with the oxidizable matter in the water towards completion is shown. This is the basis of superchlorination. By forcing the reactions towards completion by increasing both the dosage and contact time within the water treatment plant, less of the oxidizing reactions remain to be completed within the distribution system, and the residual is more stable.

In waters containing ammonia a 'breakpoint' may be observed in the chlorine demand curve. That is, a point at which a further increase in chlorine added results in an abrupt increase in the chlorine demand. In some cases, this is pronounced enough to actually give a lower chlorine residual, even though more chlorine has been added. This is the point at which the chloramines formed from the ammonia (which still react with ortho-tolidine to show a residual) break down at least in part to form the end products mentioned before,  $N_2$ ,  $N_2O$ ,  $NCl_3$  and  $Cl^-$ . Many waters containing ammonia do not exhibit ideal break point curves, due to the 'blurring' effect of the presence of other oxidizable materials.

Note: The breakpoint curve is used in example because it demonstrates neatly a number of effects of increasing chlorine dosage, and not because it is the most desirable technique to use in water treatment. The practical considerations to be assessed in choosing among marginal, free, breakpoint or super chlorination will be discussed in a subsequent lecture in this course.

In summary:

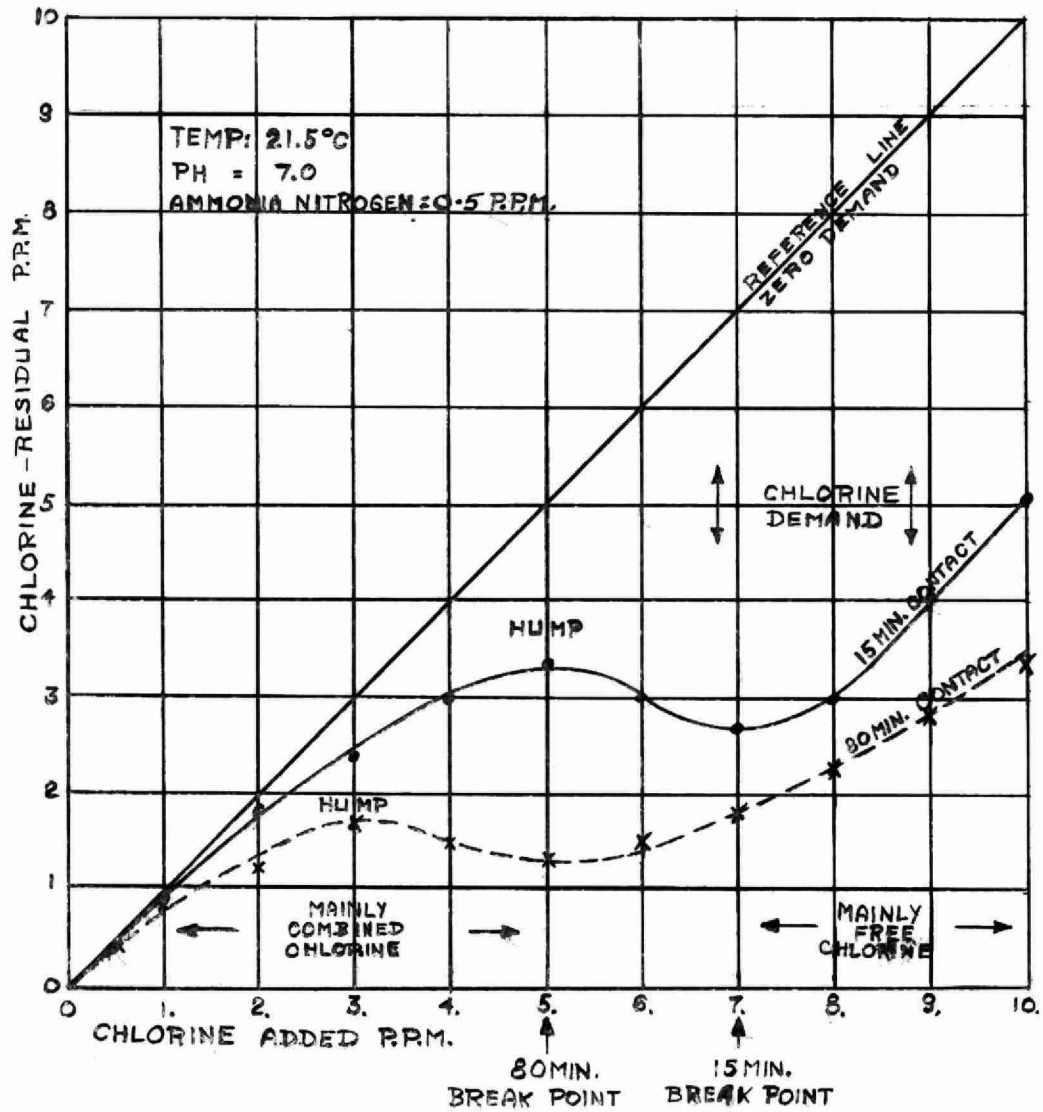
Chlorine exerts and loses its oxidizing power, and is converted to the chloride ion  $Cl^-$  by robbing oxidizable compounds of electrons. These compounds include many of the chemicals which impart objectionable properties to water, and chemicals which are vital components of many bacteria and cells. By losing electrons, these chemicals are broken down or converted into more desirable forms.

The factors influencing chlorine demand are:

- |                 |   |
|-----------------|---|
| Water quality   | - This often varies in a given water supply.  |
| pH              | - This has a distinct and sometimes adverse effect on chlorination reactions.                                   |
| Temperature     | - Rises in temperature increase the rates of chlorination reactions, hence the chlorine demand in a given time. |
| Time            | - Chlorine reactions generally progress towards completion at slower and slower rates as time passes.           |
| Chlorine Dosage | - This is the main control factor through which chlorination reactions can be hastened.                         |

# CHLORINE DEMAND GRAPH

SHOWING BREAK POINT CHLORINATION RESULTS  
OBTAINED DURING CLASS DEMONSTRATIONS



	P.P.M.										
CHLORINE ADDED	0.5	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
CHLORINE RESIDUAL AFTER 15 MIN. CONTACT	0.45	0.9	1.85	2.35	3.0	3.4	3.0	2.7	3.0	4.1	5.1
CHLORINE RESIDUAL AFTER 80 MIN. CONTACT	0.4	0.85	1.2	1.7	1.5	1.4	1.6	1.8	2.3	2.8	3.3

APPLICATION OF TASTE CONTROL METHODS  
ON WATER SUPPLIES

by

L. South

District Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

# APPLICATION OF TASTE CONTROL METHODS ON WATER SUPPLIES

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## INTRODUCTION

People tend to become used to the taste or odour of a water and as long as the quality and intensity in this regard is constant, few complaints are received from the natives. However, visitors may object strenuously to such a condition and water of this nature is not likely to attract new water using enterprises to a municipality. In addition, many laymen associate unpalatability with unsafe water.

A survey conducted by Sigworth of 241 water treatment plants, in the United States, reporting taste and odour problems indicated that carbon was effective in 86% of the cases, followed by chlorine dioxide with 25%. For this reason carbon treatment only will be discussed at this time and chemical oxidative methods will be discussed in the subsequent lecture.

## SAMPLING

Samples should be taken as often as experience indicates that a change is likely to occur. It is also possible to make this period agree with the flow through time in the sedimentation basins. On an average, samples can be drawn every four hours from the following points; raw water, settled water, filtered water and tap water.

The sampling bottles should be wide-mouthed with glass stoppers. These should be carefully cleaned and rinsed with odour-free water immediately before sampling. The samples should be stored in a cool dark place until the time of testing.

## THRESHOLD ODOUR TESTING

When it is desired to have close control on the problem the threshold odour test should be used. This test is merely a dilution of the odour bearing sample with odour free water to the point where the odour is just detectable. That is, if the sample requires dilution to 10 times its original volume then the threshold number is 10. The test is outlined in Standard Methods and will be further discussed by other lecturers.



This test is quite useful in experimenting with various chemical dosages on a sample of the raw water. It is important in testing that the operator define the odour as well as applying a threshold number. This is necessary so that the treatment efficiency can be compared for different types of odours.

#### APPLICABILITY & OPERATION DATA

Carbon should in general only be considered at plants having filters. This is in order to prevent the discharge of the material to the distribution system. In addition, the filters should be in good condition and frequent checks made for carbon in the filtrate. The maximum dosage of carbon permissible will vary at different times. Factors affecting this will be the efficiency of coagulation, i.e., in warmer weather with better coagulation and settling larger amounts of carbon can be used. Another point is to filter to waste for a short period after backwashing. This will allow some "alum gel" to build up on the filters and more effectively hold carbon particles. The carbon impregnated gel will provide a continuing adsorptive mat to the taste and/or odour waters. In addition, more care must be exercised for coarse-grained filters.

#### POINTS OF APPLICATION

Carbon can be applied at any one or combination of the following points; raw water or mixing basins, influent to settling tanks, effluent of settling tanks, and directly to the filters. In any case points of application should be chosen which will allow intimate mixing of the carbon. It is generally found that a split treatment is preferred due to the fact that adsorption is more efficient in stages.

As chlorine and carbon counteract one another some separation should be provided between their respective points of application. If carbon is applied first there should be a contact period of some 20 minutes prior to the application of chlorine.

It has been noted in some cases that chlorine tends to fix or stabilize tastes and odours in water. This is especially true at lower chlorine dosages, i.e., prior to the breakpoint. Therefore, in these cases, it would be advisable to apply the carbon ahead of the pre-chlorine. Where taste and odour treatment is necessary on a continuous basis it will be necessary to consider the development of growths in the works upstream of the point of pre-chlorination.

For mild taste and odour problems, i.e., those requiring



a carbon dosage of up to 10 ppm., the carbon can be effectively applied to the top of the filter. This gives the most prompt improvement to the plant effluent. In addition, none of the effectiveness of the carbon is lost by adsorption into the existing sludge in the settling tanks. Also, the normal treatment of coagulation and settling is allowed to remove its share of the taste and odour producing material before applying the carbon. Carbon dosages at this level do not significantly reduce filter runs.

For pronounced taste and odour problems and where they occur frequently it is more desirable to apply the carbon at the mixing or coagulation basins. It is generally advisable to apply the carbon after the floc formation. This will help to prevent the alum from coating and lowering the adsorptive ability of the carbon particles. When carbon is applied at this point the upper dosage limit is increased measurably due to the large percentage removal in the settling basins. Dosages of up to 1200 ppm. have been reported with this point of application. It is also indicated that when carbon is applied at this point, coagulation is improved and the settled sludge becomes more stable.

#### FEEDING ACTIVATED CARBON

Activated carbon can be fed either dry or in slurry form. The two terms apply to the stage of measuring as the material in either case is wet mixed before its application to the water. One of the problems associated with the use of carbon in the past has been due to dust. This has been overcome for the most part by the development of equipment wherein the bag is opened inside a dust proof container. In dry feed equipment care must be taken to prevent arching of the carbon in the hopper. For slurry feed equipment consideration must be given to keeping the mixture in suspension prior to feeding.

The following is a suggested method for the emergency slurry feeding of carbon:

Install a small diameter pipe with a gate valve at the bottom of a 40-gallon drum and place near the point of application. The drum should be half filled with water and a bag of activated carbon carefully emptied into it. It is not advisable to shake the bag for removal of the last remnants as the amount obtained is not worth the dust problem. The mixture should be left for two or three hours in order to allow time for the carbon to wet. A wood paddle can then be used for stirring the carbon into suspension. If available, a mechanical mixer can be employed. After the carbon is wetted and mixed, fill the remaining portion

of the drum with water and stir into a uniform solution. The slurry can then be gravity fed to the water. It will require frequent stirring to keep the carbon in suspension. If more than the 40 gallons of mixture is needed it will be necessary to start the preparation of a second drum some two hours prior to the emptying of the first. This is to allow for the wetting period.

#### CARBON DOSAGE

When a taste and odour problem occurs a common method of determining the correct dosage is to intermittently increase the carbon feed until a palatable water is obtained. In this method it is necessary to time the sampling periods to the correct flow through time in relation to the time of dosage adjustment.

The following is an illustration of this:

- carbon applied at inlet to settling tanks
- settling tank capacity 80,000 gallons
- pumping rate 670 gallons per minute
- sampling point at effluent of filters
- carbon dosage adjusted at 10:00 a.m.
- settling tank flow through time =  $\frac{80,000}{670} = 120$  minutes
- allowance for filters etc. = 15 minutes
- Total = 135 minutes or 2 hours and 15 minutes
- ..Filtered water should be tested at 12:15 p.m. and  
..carbon dosage adjusted.

Where the problem is severe it is generally better to overdose with carbon and slowly cut back the dosage until a palatable water is obtained.

The following is a more exact method of establishing the correct dosage:

Obtain five 1-litre samples of the odour-bearing water from a point ahead of the carbon application. Make up a stock carbon solution by adding one gram of carbon to one litre of odour and taste free water. A millilitre of this stock solution in a litre of sample is equivalent to a carbon dosage of 1 ppm. Add varying amounts of the stock carbon solution

to the water samples such as to produce dosages of 5, 10, 25 and 50 ppm. The fifth sample will serve as a blank. The samples are each agitated for 30 minutes, coagulated and filtered through glass wool. The filtrate is then tested and the lowest acceptable dosage determined. A more exact determination of the dosage can be obtained by plotting the carbon dosage against the threshold number as indicated on Fig. #1. It is generally found that plant scale treatment is more efficient than the laboratory tests. As a rule it is only necessary to apply half the dosage determined in the laboratory tests. A compromise method to the above noted systems is as follows:

Prepare a stock suspension by mixing a level teaspoon of carbon in a gallon of odour and taste free water. Add varying amounts (measured in teaspoons) of the stock solution to gallon samples of the contaminated water. As before five samples can be used. Filter the treated samples through a funnel filled with loosely packed absorbent cotton. The various filtrates can then be checked for palatability. The number of teaspoons of stock suspension added to the satisfactory sample is multiplied by 1.8 in order to obtain the carbon dose in pounds per million gallons; or multiplied by 5.5 for carbon dosage in parts per million.

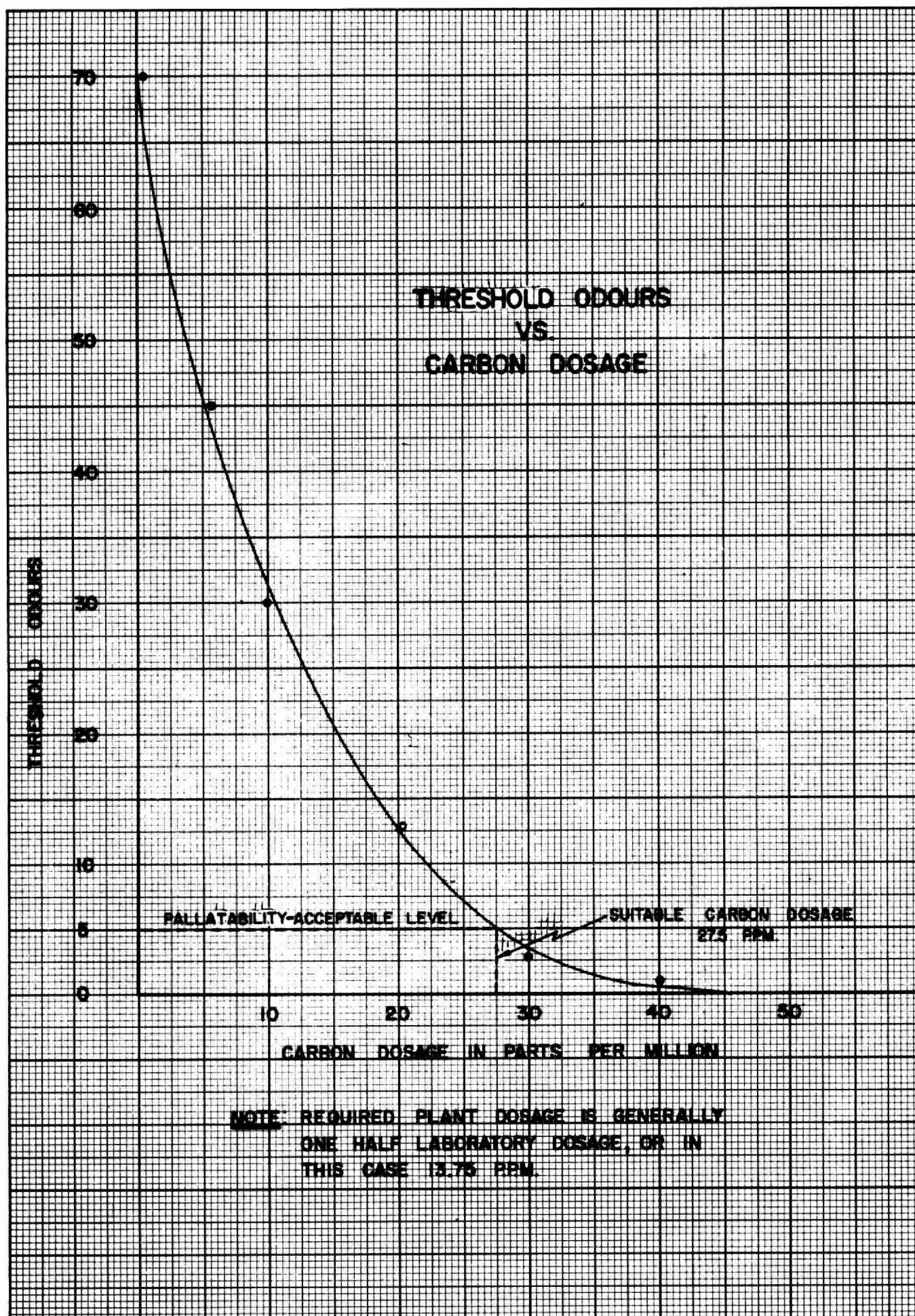
#### CARBON STORAGE

Stored activated carbon readily adsorbs vapours which will subsequently reduce its effectiveness in water treatment. For this reason the material should be stored in an area free from air contaminants such as gasoline vapours, chlorine and sulphur dioxide.

Activated carbon should be stored in a room free from sparks, machinery in operation, unprotected electric switches and wiring. "No Smoking" signs should be displayed in the storage area.

The bags should be stored off the ground and in rows so that adequate ventilation can be provided.

In case of fire a chemical foam or a water mist spray should be used. Jets of water will serve to spread the particles and fire over a greater area.



CHEMICAL FEEDERS - CHARACTERISTICS,  
CALIBRATION & MAINTENANCE

by

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Assistant District Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
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# CHEMICAL FEEDERS - CHARACTERISTICS, CALIBRATION & MAINTENANCE

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Assistant District Engineer - OWRC

## INTRODUCTION

Chemical feeding is probably the most important phase of all water treatment. Improper feeding of chemicals can only result in disastrous endings, so far as plant results are concerned. In the field of water purification, there are several treatment processes which involve the use of chemicals. Some of the more common chemical treatment processes are:

1. algae control
2. coagulation (turbidity removal)
3. colour removal
4. corrosion and scale control (stabilization)
5. disinfection
6. fluoridation
7. iron and manganese removal
8. pH adjustment
9. softening, and
10. taste and odour control.

Treatment reactions must be supplied with the right amount of chemicals at the proper strength. Many feeder designs have evolved to cover each specific treatment, but can be classified into three broad categories, namely; gas, solution and dry types.

It is the purpose of this paper to discuss the features of the various types of equipment available, methods of calibration, and in particular, suggest routine maintenance schedules and solutions to specific operating problems.

## GAS FEEDERS

Gas (chlorine, sulphur dioxide or ammonia), is most conveniently fed in special solution type feeders operating on a vacuum principle. Direct pressure type feeders are available, but

but are limited in application and not fool proof and safe as are the vacuum type feeders.

#### TYPES OF FEED

The direct feed type is applicable to locations where water under sufficient pressure cannot be made available to operate an injector such as is used for solution feed chlorinators. In the application of chlorine to water under pressure, dry feeding is limited to back pressures of approximately 25 psi. Many difficulties have been encountered in the development of a diffuser that effectively disperses the chlorine and at the same time will not be subject to clogging and the need of frequent cleaning. In sections of the province where low temperatures are encountered, chlorine hydrate formation around the diffuser may interfere with satisfactory operation. If complete diffusion is not secured, undissolved chlorine gas will accumulate in pipelines, valve heads, and pumps causing corrosion.

A solution feed chlorinator is one in which the gas is first dissolved in a minor flow of water and the resultant chlorine solution fed to the desired point of application. An operating water pressure 2 to 4 times the pressure against which the solution is to be introduced is necessary to operate the chlorine solution injector.

#### TYPES OF FEEDERS

##### 1. Vacuum Type

Vacuum type chlorine feeders meter chlorine gas, convey it through the apparatus under vacuum and employ an injector into which the gas is drawn to provide solution feed. In a full-vacuum type feeder, the vacuum governs the operation of the chlorine inlet valve. In this type of feeder which employs a direct indicating meter, the flow of chlorine is automatically shut off on loss of vacuum, stoppage of discharge line, or loss of operating water pressure.

##### 2. Partial Vacuum Type

In the partial vacuum type feeder, which usually employs a direct indicating meter, opening of the chlorine inlet valve is not vacuum governed and the feeder will not automatically shut off flow of chlorine on loss of operating water pressure, loss of vacuum or stoppage of injector.

##### 3. Pressure Type

Pressure type chlorine feeders are commonly used for direct feed. No safety is afforded against leakage since the gas is under pressure during normal operation. Pressure feed

devices consist essentially of a pressure reducing, pressure-compensating valve by which, regardless of pressure variations in chlorine cylinders due to temperature changes, a constant pressure drop may be maintained across an orifice which is measured and used as an indication of the rate of gas flow.

#### 4. Pulsating Type

Pulsating type feeders are similar to partial vacuumed type except the metering device is a volumetric pulsating unit and the rate of chlorine feed must be ascertained by timing the meter pulsations.

### PLATFORM SCALE

Although not necessary, a platform scale is very convenient for use in connection with the chlorine containers. The weight of the container is stamped on each cylinder and it is only necessary to subtract this weight from the total as indicated by the scale to tell at any instant how much chlorine there is in the container. By taking periodic readings, the operator is enabled to check the amount of gas as used each day against the amount as indicated or required by the flow of water. Chlorine tank pressure as shown on the chlorine pressure gauge is not an indication of the amount of chlorine remaining in the cylinder or cylinders. The pressure will remain reasonably constant until the container is practically empty.

### SCHEDULE OF MAINTENANCE OPERATIONS

The following notes on maintenance are applicable to gas chlorinators.

#### Inspect for Leaks (Daily)

Examine chlorinator and all piping for chlorine or water leaks. All chlorine leaks are serious, because they increase rapidly in size and cause extensive corrosion and damage. Red discolouration means scale.

To locate chlorine leaks, hold mouth of unstoppered ammonia water bottle near all joints, valves and along piping; white fumes of ammonium chloride indicate a leak. Keep ammonia bottle tightly stoppered when not in use to prevent loss of strength.

#### Operate Chlorine Valves (Daily)

Open and close all chlorine valves to prevent threads on stem from becoming set in one position. Do not use force in closing a valve. Check stuffing boxes.



### Check Gas System (Daily)

Check that all parts carrying chlorine gas are operating properly. See that metering devices, pressure-reducing and shut-off valves, tubing and so on function properly. Disassemble and clean where necessary, determining cause of fault.

### Check Vacuum Relief (Daily)

Make sure assembly operates properly and relief hose line is not plugged. Insects may plug lines.

### Clean Cabinet and Critical Working Parts (Weekly)

Thoroughly clean chlorinator cabinet, glass parts, floats, metering devices, and other parts in which dirt might interfere with operations or make equipment unsightly. All unpainted metal parts should be coated with vaseline, preferably laid on with a brush, to prevent possible external corrosion.

### Check Water System (Monthly)

Clean water strainers and check pressure-reducing valves for proper operation. See that float valves are properly controlling water levels and that leakage and splashing is at a minimum. See that water flowing to waste is not excessive and that water levels are kept at their proper elevations. See that ejectors have their original capacities. If they do not, remove and clean with muriatic acid.

### Disassemble or Operate Important Hard-rubber Threads, Valves and Parts (Quarterly)

Hard-rubber threads or parts on a chlorinator freeze or stick when not operated for long periods, causing breakage when parts are disassembled. To keep threads from freezing, operate all parts needed to keep chlorinator in service.

Caution: Use no tools on hard-rubber parts, except for rare and careful use of a strap wrench. Tighten hard-rubber parts only fingertight. Before reassembling such parts, cover with graphite grease.

### Examine Solution Tube (Annually)

Check tubing for abrasion that might cause leaks. Inspect tubing for kinks or for mineral deposits restricting discharge. Remove iron or manganese deposits from diffuser tube by adding 10 percent solution of hexametaphosphate or septaphosphate to make-up water, at rate of 1 drop per minute. To add reagent, attach rubber hose to bottle containing treatment solution, and place pinch clamp on rubber hose. Invert bottle and adjust pinch clamp for proper feed rate.

## Overhaul (Annually)

Remove chlorinator parts and clean thoroughly. Paint chlorinator cabinet inside and out with three coats of rust-resisting paint. Carefully examine each chlorinator part. Reassemble and check for proper operation.

1. The only safe liquids for cleaning chlorine lines are wood alcohol and carbon tetrachloride. After cleaning, allow it to evaporate to dryness. Ethyl alcohol or ether are converted by chlorine into solid waxy substances. Water combines with chlorine to form a highly corrosive substance.
2. Oil or grease react with chlorine to form a voluminous frothy substance. Therefore, they should not be used as lubricants at points where they may come into contact with chlorine.
3. Condensation forming on chlorine cylinder walls may corrode scales and other equipment around the cylinder. Guard against such damage by improved ventilation around the cylinder to keep surfaces dry. An electric fan may suffice. Do not apply direct heat to dry the cylinder.
4. It is dangerous to attempt to increase the rate of gas withdrawal by heating chlorine cylinders or containers above normal room temperature with hot water baths or other means. Inspect regularly to see that chlorine cylinders are not near steam, hot water lines, or other sources of heat.
5. Use a new lead gasket in connecting valve or tube and when replacing empty chlorine cylinders. Use only one lead gasket.

## SOLUTION FEEDERS

Solution feeders may be non-positive or positive displacement. Non-positive displacement solution feeders include decanters, orifice rotameter and crystal solution types. Positive displacement feeders include the rotating dipper and proportional pumps.

A solution feeder is always preceded by a dissolving tank.

The following discussion will be limited to hypochlorite feeding equipment since the increased use of more stable hypochlorites has led to the design of a large number of ingenious chemical feed devices.

The majority of these feeders take the form of a positive displacement solution pump, utilizing either a diaphragm or piston as the main pumping element. The amount of solution pumped can be varied by changing either the length of stroke, number of strokes per minute, or a combination of both.

Commercial hypochlorite feeders are generally operated either by electricity or water pressure. Further design features usually also provide for either manual or automatic operation. In manual operation the dosage must be changed by the operator, while automatic operation is usually accomplished by means of a displacement meter in the main pipeline, or by means of a small meter installed in a bypass around an orifice plate or venturi tube.

Although the initial investment in control equipment is lower, it is more expensive to use chlorine compounds as a source of chlorine than to use gaseous chlorine. Hypochlorites are widely used where the consumption of water is so small that the cost of chlorine is of little consequence.

#### SCHEDULE OF MAINTENANCE OPERATIONS

The following notes on maintenance operations are applicable to both pumptype and proportional type solution feeders.

##### Check Operation (Daily)

Inspect sight-feed indicators to ensure that solution is being fed.

1. See that automatic controls start and stop properly.
2. Check sufficiency of prepared solution.
3. Check for leaks in piping joints and packing glands.

##### Clean Feeder (Weekly)

Remove and clean glass and plastic parts of sight-feed indicator. Remove white coating caused by hard water in hypochlorite solutions by soaking in 5 percent solution of muriatic acid.

1. Clean and flush solution tank or solid chemical dissolving compartment.
2. Clean screens and strainers on water lines.
3. Operate all shut-off and rate-control valves.

##### Overhaul Feeder (Annually)

1. Remove, inspect and replace all worn parts and packing.
2. Clean all orifice plates, needle valves, screen in water meter, etc.
3. Touch up all metal parts with paint.

## DRY FEEDERS

There are two basic types of dry feeding mechanisms--volumetric and gravimetric.

Volumetric feeders are designed for volume displacement. Scales are not a part of volumetric feed mechanisms, although they may be provided for calibration of the equipment. Also, platform scales may be used to support the entire machine and its contents to provide a record of chemicals discharged. In this case, the scales do not control the rate of feed, but do permit a reasonable check on machine performance.

Change in bulk density or feeding characteristics of the chemical being handled directly affect the actual weight of the material delivered. Since volumetric feeders can measure only the volume displaced and not material weight, there is no provision for warning the operator if the chemical is not being fed. It is possible for volumetric equipment to operate mechanically without delivering chemical. Volumetric feeders usually require close attention from plant operators to ensure continuous operation at acceptable efficiency. They are used in small plants where rate of operation is relatively constant, regular performance checks of equipment operations can be made, and retention capacity of mixing and settling basins is sufficiently large to offset feed variations caused by changes in chemical bulk density or feeding characteristics. The potential accuracy of feed rate control with standard volumetric equipment is  $\pm 3-5\%$  (by weight) under average conditions, but  $\pm 10\%$  deviations from preset rates may be anticipated with normal variations in chemical characteristics and operating attention.

Gravimetric feeders, which incorporate accurate weighing devices, are designed to feed dry chemicals continuously by weight. Because of their improved accuracy in controlling feed rate, wider feed range and their suitability for combination with recorders, totalizers and automatic controls, they are preferred over volumetric units. Generally, the rate of feed is independent of bulk density or flow characteristics of the chemical being fed, although materials having caking or flooding tendencies cause difficulty in regulation of feed. These units are designed so that when the feed rate has been preset, the feeder will maintain this rate of feed by weight control, within reasonable limits. The guaranteed accuracy of gravimetric feeders is  $\pm 1\%$  by weight.

### TYPES OF VOLUMETRIC FEEDERS

Volumetric feeders may be sub-divided into three major types based on the principle of operation.

## Oscillating Hopper and Tray Type

This is probably the most familiar type of chemical feeder in the volumetric field. In general, these feeders incorporate a motor driven oscillating hopper which continuously discharges a ribbon of chemical from a feeder tray suspended beneath the hopper. Adjustments in rate of feed are made by varying the length of stroke; that is, the amplitude of the oscillator of the hopper and/or the depth of the ribbon discharged from the tray.

### Disc Type

This feeder incorporates a continuously revolving disc operating under a storage hopper. The material is then discharged at this portion of the disc. Feed adjustments to this type of feeder are made by varying the gate opening which varies the depth of material carried by the disc and/or varying the speed of rotation of the disc. This feeder is very suitable for feeding at low feed rates. In all these units, delivery rates are regulated by clutch mechanisms, adjustable gears, or cams which can be manually adjusted during service to change speed of rotation, ribbon thickness, or feed blade setting.

### Rotary Type

This feeder consists of a continuously rotating drum with a series of feed pockets. The drum rotates beneath a storage hopper and discharges the volume of the individual pockets as each pocket rotates out from under the storage hopper. Feed adjustment of this machine is normally made by varying the speed of rotation of the rotor. Feeders of this type are normally used for feeding materials which have a tendency to arch and flood since the rotary mechanism is positive protection against flooding of chemicals. This type of feeder has been widely used for feeding activated carbon. These units can be combined with rate-setting devices to permit their application to automatic pH control or variable flow systems.

## TYPES OF GRAVIMETRIC FEEDERS

Gravimetric feeders are manufactured in two basic types, the loss-in-weight and belt gravimetric units. Regardless of type, every gravimetric feeder must include a weight sensing element, a feed mechanism, and a controller. The scale and feeding mechanisms in all units are reasonably standard. However, the method and complexity of control mechanisms vary widely.

### Loss-in-weight Type

In this type of feeder, the entire feeder hopper is suspended on a scale system. The feeder then releases or feeds



material from the feeder hopper so that the loss of weight of material in the hopper is controlled to equal whatever feed rate has been set to the machine. The feed rate is determined by the rate at which a mechanically-driven lead screw retracts the counterweight on the scale beam. Changes in feed rate are made by varying this speed of retraction. Loss-in-weight feeders never need to be calibrated even on initial start up since the scale system itself is an accurate weighing device.

### Belt Type

In a typical belt gravimetric feeder, dry chemical enters the feeder at the top through a chute or hopper and passes to the feed mechanism. Here it is fed to a weigh belt supported on a scale. This small moving belt delivers the dry chemical to the feeder outlet or dissolving tank. The scale controls the feeding mechanism so as to maintain a uniform weight of chemical on the weigh belt, regardless of changes in the bulk density. Belt gravimetric feeders must be calibrated by catching samples on initial installation. Once calibrated however, a belt feeder need not be calibrated again since the initial calibration data will continue to hold true.

Feed rate adjustments may be made in two ways:

1. By adjusting the scale beam counterweight to increase or decrease weight on the weigh belt, while allowing the belt to run at a constant speed.
2. By varying belt speed while maintaining constant chemical weight on the weigh belt. The scale beam is combined with rate control devices such as vibrators, to regulate operation of the feed tray which delivers chemical to the weigh belt. As an alternative, control may be obtained by variations in feed gate opening to maintain a preset feed rate from the weigh belt.

### SCHEDULE OF MAINTENANCE OPERATIONS

The following notes are applicable to volumetric dry feeders:

#### Clean and Inspect (Daily)

Clean feeder, feeder mechanism, and feeder surroundings. Remove spilled chemical and chemical-dust accumulations with vacuum cleaner or brush. Look for oil drips, wiring defects, and deterioration. Observe general performance of feeder. Note and investigate unusual noises. See that orifice, knife edges, scrapers, shakers, and openings are free of chemical accumulations.

Probe solution tank for sediment or undissolved chemical and make necessary corrections. Be sure that hopper fills are made without chemical spillage on working parts of feeder. If chemical feeder is out of service, see that feeder is empty of chemical and that condensation is not causing deterioration.

#### Inspect for Loose Bolts and Cracks (Weekly)

Carefully wipe all parts of feeder. Inspect for loose bolts, cracks, defective parts, and leaks.

#### Test Calibration (Monthly)

Make several calibration tests, using range of feed in which chemical feeder operates most frequently, to check accuracy of rate setting devices, charts, or tables.

1. Test with feeder not on scale. With chemical feeder off scale and delivering uniformly after a change in rate of feed, catch delivery in pan for a known period of time. Weigh material caught and calculate feed in pounds per hour. Compare with indicated rate setting on chart. Be careful and accurate in timing, weighing and collecting material. Perform each test several times to check results.
2. Test with feeder on scale. With feeder on weighing scale, check rate of feed by stopping feeder, balancing scales, and then running feeder for a known period of time. Stop feeder and rebalance scale. Subtract this reading from previous scale reading to determine amount of chemical that passed through hopper in the given time.

#### Overhaul (Annually)

Overhaul chemical feeder, clean and paint interior and exterior. Clean and repair solution and make-up tanks. Service drive-mechanism bearings and other mechanical parts.

The following notes on maintenance are applicable to gravimetric belt type dry feeders, and also the loss-in-weight type except for the description of the delivery test.

#### Clean, Check and Test Balance (Daily)

Clean feeder, feeder mechanism, and surroundings. Empty feed belt, clean off accumulations, and test scale balance with zero load. Make necessary adjustments to correct tare-weight balance. Check for mechanical and electrical defects and for proper operation. Look for oil drips and wiring defects. Observe general performance and investigate unusual noises. Make sure chemical is not accumulating on inner roll of belt or adhering to



belt in a manner which may cause too high a tension or tare. Check solution tank and the feeder out of service as pointed out previously for volumetric feeders.

#### Inspect for Loose-Bolts and Defective Parts (Weekly)

Carefully wipe all parts of feeder inspecting for loose bolts, leaks, defective parts, and so on. Check belt tension.

#### Make Delivery Test (Monthly)

To locate feeder abnormalities, test delivery of feeder to see that its actual output is equal to weight indication totalizer or integration device.

1. Clean belt and feeder and then balance scale. Return feeder to service and operate until chemical forms an even, uniform layer on feeder belt and scale remains in close balance. See that poise on scale beam indicates proper load on belt.
2. Stop motor. See that scale with its load of material moves freely and is in exact balance. If it is not, add or remove material from rear end of load on belt until exact balance is obtained.
3. Disengage or stop operation of mechanism which feeds chemical to belt. Read belt revolution counter or weight integrator. Then operate feeder belt until counter or weight integrator indicates that exactly a predetermined number of pounds of chemical, about two-thirds of belt loading, have been fed. Stop feeder instantly by turning off motor switch.
4. Again see that scale can move freely and then move poise to bring scale back to exact balance. Note scale reading. The difference between this scale reading and initial scale reading gives exact weight of material which has been delivered.
5. If this reading does not coincide with number of pounds as shown by revolution counter, adjust as follows:
  - (a) If actual delivery as shown by front scale beam is greater than indicated by revolution counter, move poise on scale beam to a lower figure so belt loading is less, then repeat test.
  - (b) If actual delivery is less than indicated by revolution counter, move scale poise to higher reading on scale beam so belt loading is greater and repeat test.

6. Continue testing until a belt loading is found which results in delivery of material corresponding exactly with reading of revolution counter. When this location is determined, set and change poise on scale beam at this position, and record setting for future reference. Thereafter when feeding same sort of material, use same belt loading. Recalibrate when using a different type of material which has a different degree of slope at which material falls off front end of feeder belt.

Note: For certain other belt type feeders, a delivery test can only be made by catching delivery during an exact test period and weighing the catch. Actual delivery rate of feeder can be calculated from these data.

#### Overhaul Feeder (Annually)

Remove feeder-belt assembly, motors, belts, and the like where practical and overhaul feeder completely. Clean and paint entire structure. Clean scales, and edges and test for sensitivity. Lubricate all mechanical parts, and make necessary repairs.

### NOMOGRAM AIDS

Operating control nomograms are often useful in calculating chemical dosages and may also be used to check feeding accuracy. In the following appendix there are two nomograms provided, one regarding chlorination treatment and the other dry chemical feed machines. Also included is a description of the use of these nomograms and solutions to example problems.

### APPENDIX

#### I - Chlorination Nomogram

This Nomogram for chlorination control has been developed primarily to aid in determining the proper setting of chlorine gas feeders for use in the treatment of water ( or sewage and industrial wastes). However, most dry and liquid chemical feed calculations involve consideration of the same factors applicable to chlorine feed, hence, it is apparent the nomogram has broad use and application.

#### APPLICATIONS

##### 1. Design Work

For determining the maximum capacity of chlorination equipment needed.--If the chlorine requirement of the

liquid to be treated is known (or if some value is set as maximum requirement in p.p.m. by a governmental control agency), and if the maximum expected flow is known or can be estimated, the nomogram affords a simple means of determining maximum feed rate required.

## 2. In Operation and Control

As an aid in setting chlorine feed rates.--Having established by chemical tests the chlorine dosage required to effect a desired residual, the nomogram may be employed to determine the proper chlorine feeder setting to produce that residual at any given flow rate.

## 3. In Plant Performance

To accurately and quickly convert accumulated "known" data into average performance and to readily transpose momentary feed and flow rates to dosage in p.p.m. From the flow measuring device, accumulated flows over a selected period or momentary flow may be determined. Chlorine flow totalizers or loss-in-weight measurements of containers on scales provide accumulated feed information and chlorine recorders or the chlorine feeder indicates momentary feed rate in lbs. per 24 hrs. With these data applied to lines C and A, the chlorine dosage in p.p.m. may be read on line B.

## EXAMPLES OF USE

### 1. Direct Reading

For a flow of 0.8 mgd (556 gpm) with a chlorine requirement of 1.1 p.p.m., place straight-edge on 0.8 on line A and on 1.1 on line B. (Note that angle with line B is approximately a right angle and therefore is satisfactory). Read value of 7.35 on line C. Setting for chlorine feeder is 7.35 lb. per 24 hr.

### 2. Single Multiplier

Where the straight-edge nearly parallels line B.--For a flow of 0.2 mgd (139 gpm) with a chlorine requirement of 0.1 p.p.m., place straight-edge on 0.2 on line A and on 0.1 on line B. Note that the angle of the straight-edge with line B is far from a right angle. Therefore, for more accurate results, place straight-edge on 0.2 on line A and on 1.0 on line B and read value of 1.67 on line C. Multiply this value by 0.1. Setting for chlorine feeder is .167 per 24 hr.

### 3. Single Multiplier

Where straight-edge does not cross line C.--For a flow of 0.7 mgd with a chlorine requirement of 2.5 p.p.m., note that the straight-edge does not cross line C. Therefore, place straight-edge on 0.7 on line A and on 0.25 on line B. Read value of 1.45 on line C. Multiply this value by 10. Setting for chlorine feeder is 14.5 lb. per 24 hr.

Note: Straight-edge approaches right angle with line B for this placement and is therefore, more accurate than using 0.07 on line A and 2.5 on line B, which would give the same value on line C at 1.45.

### 4. Single Multiplier

For normal placement of straight-edge.--For a flow of 7.0 mgd with a chlorine requirement of 0.6 p.p.m., place straight-edge on 0.7 on line A and on 0.6 on line B. Read value of 3.5 on line C. Multiply this value by factor of 10. (Factor of 10 introduced on line A). Setting for chlorine feeder is 35 lb. per 24 hr.

The procedure would be the same for a flow of 70 mgd or 700 mgd, etc., using multiplier factors of 100, 1,000, etc.

### 5. Double Multipliers

For conditions where factors are introduced in both lines A and B.--For a flow of 1.7 mgd with a chlorine requirement of 8.0 p.p.m., place a straight-edge on 0.17 on line A and on 0.8 on line B. (Note, if straight-edge were placed on 8.0 on line B, it would not cross line C.) Read value of 1.13 on line C. Multiply this value by 100 (factor of 10 on line A, times factor of 10 on line B.) Setting for chlorine feeder is 113 lb. per 24 hr.

The same procedure would be followed for a flow of 17 mgd with a chlorine requirement of 13 p.p.m., in which case the straight-edge would be placed on 0.17 on line A and on 1.3 on line B. The value on line C of 1.84 would then be multiplied by 1,000 (factor of 100 on line A, times factor of 10 on line B).

### 6. Determination of Dosage

From a recorded flow rate and chlorine feed rate.--For a flow of 0.63 mgd and a chlorine feed rate of 5.8 lb. per 24 hr., place the straight-edge on 0.63 on line A

and on 5.8 on line C. Read value of 1.1 on line B.  
Chlorine dosage is 1.1 p.p.m.

This operation may also be used for values of flow and chlorine used greater than the values on lines A and C, by introducing the proper factors of 10, 100, etc.

Note: This nomogram is based on U.S. gallons. If Imperial Gallons are applicable, the following conversion factors should be used:

1 U.S. Gallon = 0.83 Imp. Gallons  
1 Imp. Gallon = 1.2 U.S. Gallons

## II - CHECKING CHART

### For Dry Chemical Feed Machines

#### EXPLANATION OF CHART

The chart shown herewith offers a convenient means to check on the delivery of dry feed machines when the pumpage rate and the desired dosage is known. Rate of feed is expressed in grams per minute to enable weighing a timed discharge to check the feeder setting, and in pounds per hour to figure quickly the quantity needed in the hopper for each expected hour of operation. Chlorine dosage may be read knowing the change in platform scale readings per hour and the flow.

Parallel scales along each axis allow rapid conversion from one system of expression to another. On the vertical axis grains per gallon, parts per million and pounds per million gallons are quickly related by scanning directly across the scales. Gallons per minute and million gallons per day are similarly converted along the horizontal scale. In the plot, grams per minute and pounds per hour are interchangeable across the diagonal scales. Pounds per hour is more logical from an operator's viewpoint than pounds per day. Many small plants operate only part of a day, or have a limited number of pumping steps, in which case pounds per day is merely a bookkeeping quantity.

A wide range in coverage is provided by the logarithmic divisions. High values not included on the chart may be read by using a tenth or hundredth of the quantity and applying the corresponding multiplier to the reading.

#### EXAMPLE

How many grams per minute must be discharged from a dry feeder to give a 2 grain per gallon dosage while operating a 300 gallon per minute system?

## SOLUTION

Find the point where the 2 grain per gallon line and the 300 gallon per minute vertical intersect. This point lies between the 35 and 40 gram per minute diagonals at about 38 grams per minute. By projecting this value across the diagonal scales, the hourly chemical consumption of 5.0 pounds is read.

When the answer falls in the area occupied by pounds per hour, diagonal readings are converted to grams per minute by projecting in the same manner across the oblique scale.

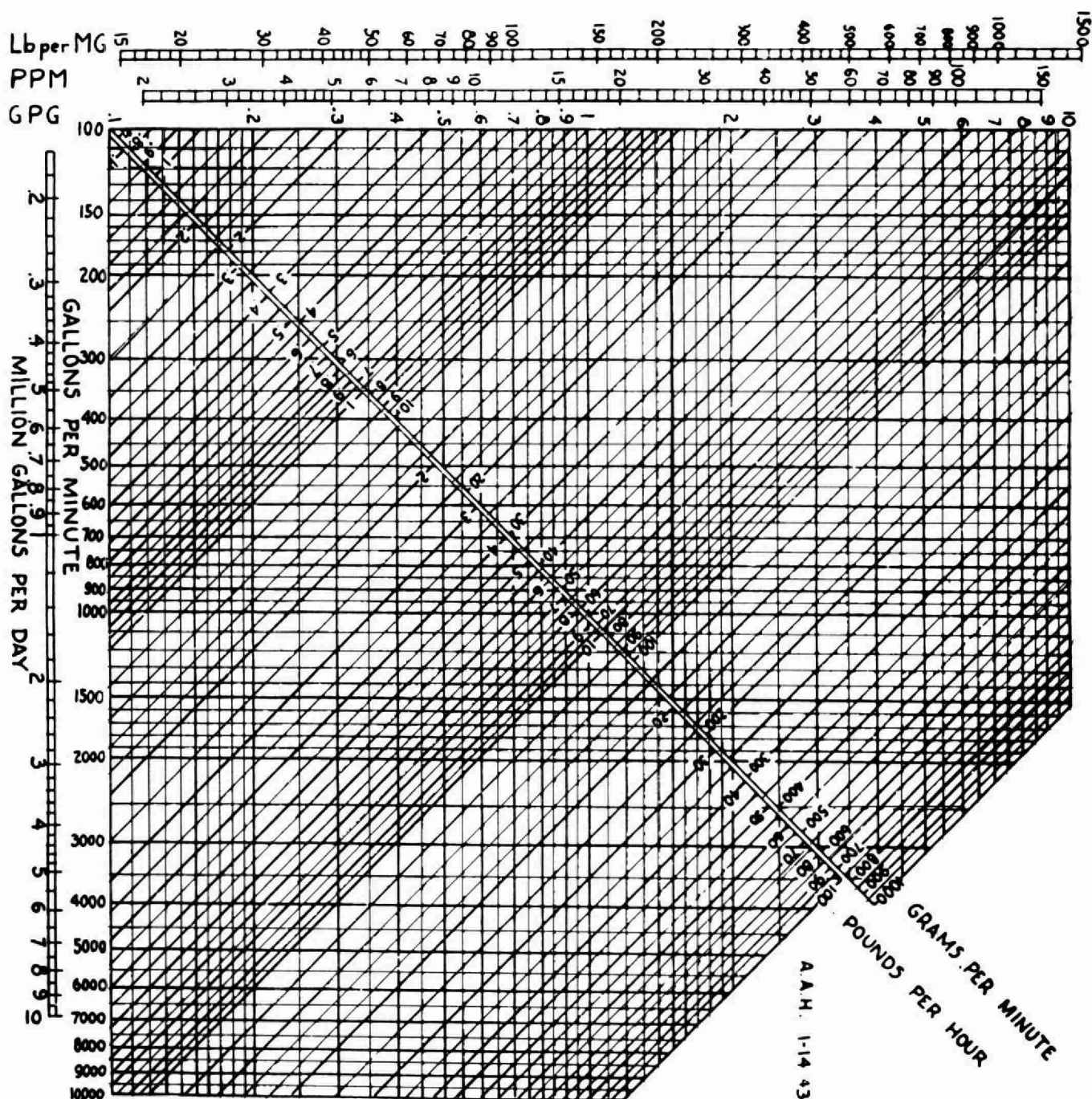
When a metric scale is unavailable, grams per minute may be obtained directly by catching the dry feeder discharge for 170 seconds and multiplying the weight in ounces by 10.



# Checking Chart For Dry Chemical Feed Machines

By A. A. HIRSCH

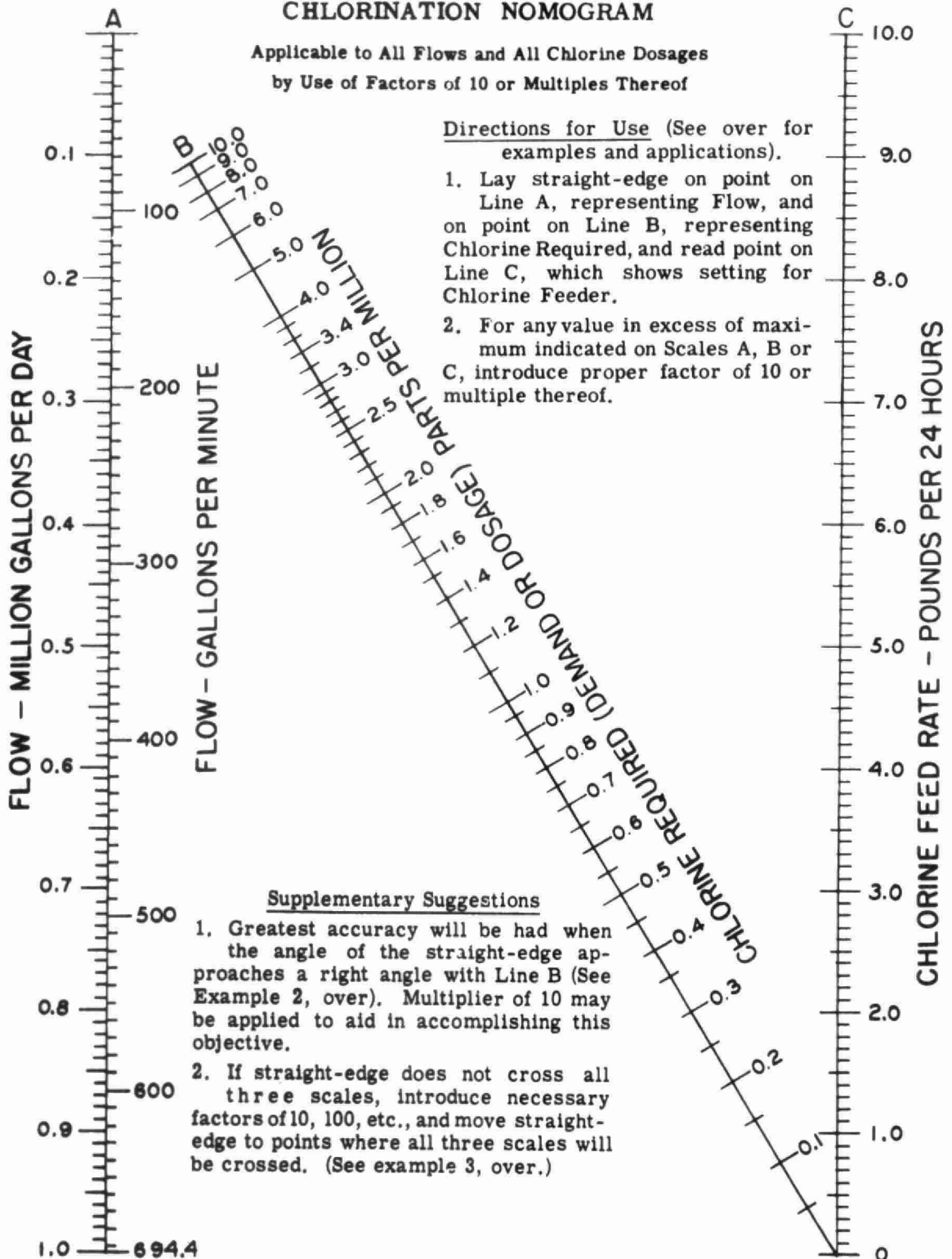
State Department of Education, Baton Rouge, Louisiana





## CHLORINATION NOMOGRAM

Applicable to All Flows and All Chlorine Dosages  
by Use of Factors of 10 or Multiples Thereof



MAINTENANCE OF VALVES, LOSS OF HEAD GAUGES  
RATE OF FLOW CONTROLLERS AND OTHER  
MECHANICAL DEVICES AT WATER TREATMENT PLANTS

by

C. W. Perry

Supervisor - Water Works - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

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In order to meet the system requirements, most water works operators find it necessary to use all of their equipment in their daily operation. Therefore, to avoid the embarrassment of water shortages, it is most necessary to keep all equipment operating properly.

Orderly maintenance and preventative maintenance is the cheapest insurance against costly equipment failure. Lack of this results in costly repairs and breakdowns to vitally needed equipment.

The prerequisites of good plant maintenance are:

1. A thorough knowledge of the equipment
2. Proper tools, and
3. Adequate repair parts

The knowledge of your equipment can be obtained from the instruction manuals issued by the maker of the equipment. Special tools for certain units should be obtained from the manufacturer and an adequate supply of properly sized common shop tools are needed for efficient maintenance procedures. Repair parts should be stocked according to the number of machines or equipment installed and the expected operating life of the equipment parts.

The amount of maintenance required to keep equipment operating efficiently can be minimized if routine maintenance is started at installation time instead of waiting for equipment failure or breakdown.

I am going to refer to routine maintenance by operators of equipment ordinarily found in most filter pipe galleries and plants. Equipment manufactures usually supply procedures for maintenance jobs which are routinely done by the operator such as air purging, oiling, mercury weighing, calibration of instruments using mercury and water manometer check equipment.

Filter loss of head gauges, rate of flow gauges and rate of flow controllers normally have one thing in common and that is a mercury chamber. This is the most important part of their operation and therefore should receive the most maintenance and care. All the chambers have a supply of mercury-- so let's talk

about mercury.

Mercury used in these chambers must be pure and free from other metals with which it amalgamates. If the mercury shows signs of sticking to the chamber parts, you have a pretty good sign of impure mercury and it should then be removed and washed in a shallow glass or plastic vessel. To wash, it first, use a concentrated solution of caustic potash, then a 25% solution of nitric acid and finally with distilled water. Never use galvanized or tin containers or funnels—use only glass, bakelite or plastic to avoid contamination of the mercury by amalgamation.

Operators handling mercury must always bear in mind the toxic effect of this element, an exposed surface of only 4 square inches under normal atmospheric conditions can produce a toxic concentration in a small work room in only a few minutes. Therefore, mercury should be handled only in well ventilated rooms especially during the washing or cleaning operation as normally large areas are exposed during this process. Mercury taken internally is extremely poisonous and destroys the cells of the kidneys; the antidote is whites of eggs. Spillage should be avoided and should be handled over trays with raised edges.

If mercury is spilled during a filling operation, the chamber should be thoroughly drained, the mercury reweighed accurately and the chamber refilled.

Most of the maintenance of a mercury meter will be in keeping the pressure connections tight and the meter body clean. Valves that come in contact with mercury should be stainless steel needle valves and not brass gate valves. Pipe lines must slope from the mercury chamber to the Venturi and some sort of a mercury trap should be installed in this line. Connections should be made on the side of the Venturi and not on the top or bottom; air could enter from a top connection and sand or grit from a bottom connection.

Most mercury chambers must be purged of air at regular intervals. This is usually determined by the accuracy of the metering equipment. If the gauge is not reading accurately, the mercury level and quality must be checked. If small drops of mercury are found around the mercury chamber meter, it is usually an indication of a leak and the mercury from that meter should be drained and re-weighed. The weight of mercury required is usually marked on the chamber. Therefore, an accurate set of scales should be available.

## LOSS OF HEAD GAUGES

This gauge indicates, by direct reading, the loss of head through the filter bed. This is controlled by the movement of a float in a mercury chamber. The level of the mercury is controlled by the effective difference in head between the water over the bed and that in the effluent line from the filter, by correctly designing the chamber, the movement of the float is directly proportioned to this difference. The movement of the float is transmitted to the gauge either by cables or by pneumatic transmission.. The cables are usually phosphor bronze and should be inspected frequently and protected from corrosion with some protective coating such as vaseline or similar compound. The mud leg should be regularly cleaned to prevent sludge or silt from entering the mercury chamber.

## RATE OF FLOW GAUGES

This gauge consists essentially of a differential producing device, usually a Venturi tube, which measures the flow of water and operates the mercury chamber. This chamber translates the differential pressure at the tube into a proportional movement which is transmitted to the gauge head and records the flow through the Venturi tube. The connections to the Venturi tube should be purged and cleaned periodically to keep scale and other foreign matter from closing the openings. Vent holes in the annular chamber may be kept clear by manually operated devices or by systems of continuous or intermittent flushing. If the vents and other connections are plugged, you are running a good chance of having an inaccurate meter. If heavy scaling conditions are encountered in the Venturi, it may be advisable to consider a Venturi by-pass and a means of descaling the Venturi throat.

## RATE OF FLOW CONTROLLERS

The rate of flow controller regulates the size of the discharge opening, which in turn, regulates the flow of water from the filter at a uniform rate, compensating for the loss in head through the filter. The controller is essentially a valve controlled by the rate of flow as determined by a differential producing device, normally a Venturi tube. This may be incorporated as one unit as in a mechanically operated balanced valve control chamber or by a butterfly valve actuated and adjusted hydraulically, pneumatically or electrically. In any case, it is normally placed after the Venturi. The reason for this being that if a filter run is continued until there is a negative head in the Venturi tube, air may be drawn into the pipe lines leading to the mercury chambers and unless lines slope so this air can be released back to the tube, the gauge may not be accurate. In a direct acting controller, air collecting

in the top must be purged, sand or silt must also be purged from below the rubber diaphragm. Occasionally these diaphragms break and replacement is necessary. These must be handled carefully and the surfaces touching metal must be coated with a mixture of flake graphite and water. The valve stem leaving the valve must float through its gland or stuffing box of its own weight.

In the majority of cases, the Venturi tubes controlling the rate of flow controllers and rate of flow gauges are located in the filter pipe gallery, because of the excessive condensation prone to form in this area, external cleanliness is a must on these Venturi tubes as it is on other metering equipment located in these areas. Painting of the gallery with a moisture and mildew resistant paint prevents corrosion from starting. This also is an incentive to keep the plant clean and attractive. Insulation or lagging these lines has been used most successfully in reducing condensation and the resulting corrosion.

All controllers that use pilot valves should have some kind of strainer, cloth is most satisfactory, to catch the fine particles of grit and sand which could foul and wear the finely machined surfaces. When the flow through a pilot valve becomes fouled, the plug is removed from the strainer and flushed with clean water; if the strainer or cloth is damaged a new strainer must be installed. If it is found that water passes through the pilot valve without moving the control valve, it is probable that the trouble is in the controller hydraulic cylinder. The leather cups on the piston should first be checked. If water continues to pass through the pilot valve, it is an indication that the pilot piston and sleeve are drawn and worn. This calls for a complete replacement. If the controller maintains a higher rate than that set, it indicates that there is either a rupture or break in the diaphragm which must be replaced.

If the control valve is of the butterfly type, the rubber seats may require change when it is worn or damaged by some foreign object. The leather piston cups in the cylinders of hydraulically operated valves wear according to time and usage, and you will occasionally be faced with their replacement. When this is done, the cylinder walls should always be cleaned and polished so that new cups will not be scored and cause leakage.

#### PNEUMATIC SIGNAL TRANSMISSION

In many newer and later designed plants, signal transmission from the mercury chambers is accomplished pneumatically. This involves an air supply normally in the form of a compressor



which is electrically driven but usually has an emergency source of power such as a gasoline or diesel engine which may be started either manually or automatically in case of power failure. The prime source of trouble in such a system is moisture. Moisture must be kept out of the system at any cost. The presence of moisture cannot be prevented but it can and must be kept out of the system. The place to start is at the compressor, all water must be blown out of the air storage tank at least daily. The supply lines leaving the receiver usually are fitted with an air filter and another water separator. These should receive the same attention as your storage tank-blow it daily. In some cases, it may be necessary to install refrigeration equipment to remove even more moisture from the system. If the system is not working satisfactorily after all checks have been made and precautions taken to remove any moisture, check the supply. All regulators should be checked for moisture and to see that the correct air pressure is being maintained, then check all joints for leaks, fittings or places where vibration or wear could cause tubing or piping failure. This is simply done with a soap and water solution watching for bubbles. It is also a good idea to check the diaphragm chambers of the air positioners or for clogging of the air escapement ports.

When using a controlled air pressure converter and operating problems are encountered... the water lines from the filter or Venturi should be checked. These lines some times become clogged and therefore should be flushed until clean. All air should be vented from the water chambers of the converter periodically. When venting this air, the vents should never be opened until the controller valve is closed, otherwise air may be drawn into the line instead of expelling it.

The calibration of a rate of flow converter, a loss of head converter or any other pressure differential converter is a tricky proposition. Reference should be made to the manufacturer and the correct calibration chart, gauges and regulators used. Incidentally, a small amount of fine machine oil on the gear trains in gauges reduces friction and possible error in calibration. The gear trains should be cleaned of lint or other foreign matter before oiling. Meter bearings should receive the same treatment. A special oil can usually be obtained from the manufacturer or they can give you a recommendation as to the type of oil to be used.

## VALVES

Your plant is equipped with a multitude of valves but they will probably fall into three or four categories; gate valves, globe valves, butterfly valves, diaphragm valves, needle valves, plug valves and penstocks. Some you may have several of, some you may have none of. In practically every type of valve with the exception of possibly the penstock, there



is one thing in common, that is, a stuffing box or gland around the valve stem. The packing of this stuffing box or gland is an important feature of good plant maintenance. A leaking valve cannot only cause trouble in the valve, but will contribute to difficulty in general housekeeping. I doubt very much as to whether you will ever get two maintenance men or operators to agree on the details of how to repack a gland, although most will agree on the following suggestions for repacking a gland in a general way:

1. All old packing should be removed from the gland.
2. Packing must be kept clean during installation because the valve stems and rods can be scored from grit or dirt picked up by the packing.
3. The stuffing box on the stem should be thoroughly cleaned after the old packing has been removed and kept clean during the repacking operation.
4. The correct size of packing should be used-this can be determined by checking the diameter of the valve stem and the inside diameter of the stuffing box. There is a definite reason for this, oversize packing is difficult to install and may cause excessive friction. Undersize packing may be ruined by too much take-up. All new clean packing should be used, old packing may be dry, highly compressed or distorted, have high friction and may be contaminated with dirt or grit and lead to scoring of the stem.
5. A length of packing should never be wound into the gland and only ring form should be used.
6. A ring from the packing should be cut, by using either the shaft or a mandril of the same size as the one on which the packing is to be used, in order to get close fitting rings.
7. Sharp clean cuts should be made, fraying on the ends of the rings should be avoided.
8. All packing ring joints should be cut to a snug fit, making the ends meet with a butt or level joint.
9. Each ring should be carefully seated before placing the next ring in the box.
10. All rings should be installed so that the joints are staggered and kept at least 90° apart. As a tip always place your packing rings with the joints staggered in a

clockwise direction to make it easier to locate them when removing the packing at a later date.

11. The follower should be pulled up sufficiently tight after re-packing to ensure final seating of the new packing. The gland nuts should be backed off to relieve excess pressure and then adjusted to operating conditions. Some operators cut an extra ring and keep it near the gland, carefully wrapped to prevent soiling, so that an additional ring may be quickly slipped in if required at a later date. A word of caution - use the right packing in the right place for the conditions under which the packing is to be used. I would suggest your consulting the packing manufacturer and get his recommendations. When old packing is removed, always use the proper tools as otherwise the box or stem or both may be scored making a tight gland impossible. You are all acquainted with the common gate or sluice valve and know that seat rings and wedge surfaces may become scored or even eroded either through water action or corrosion. In the larger valves the seat rings can be unscrewed or unbolted and removed through the bonnet of the valve, the seat ring may be trued on a lathe or lapped with a lapping compound. If heavily scored, replacement may be necessary. This same treatment is applicable to swing check valves. While the valve is apart, check stem and clean and polish this if necessary. When this is accomplished it will be necessary to reassemble the valve and sheet packing will be necessary, not only on the bonnet joint, but probably on the valve flange connections. A heavier sheet packing than necessary should never be used, the thinner the gasket material the better. Here again the correct type of gasket material should be used. Ring gaskets are preferable to full face gaskets if the flanges are heavy enough to prevent distortion. Great care should be used when it is felt necessary to use gasket dopes. Oil or grease should never be used on rubber or rubber compound gaskets. Graphite and water or glycerine may be used. Dope should never be used on both sides of a gasket; it may cause slippage and blowout. All valves should be operated at intervals through their full range open to shut or shut to open. This will not only assure the operator that the valve is operable and not stuck, but will also tend to flush out any sediment or debris which might be in the valve.

You may or may not have plug valves in your plant, but these valves can give you nothing but trouble if not maintained and inspected regularly. We have found that the best way to maintain them is to use them. They have a tendency to jam or freeze due to their very design. Most of them are wedge or

conical shaped and to keep them tight, a considerable tension must be put on the plug. Frequent operation will break any tendency for the closely fitted surfaces to corrode together. Most of them have some system of force lubrication either by stick lubricant forced in the top by a screw or a fitting to take a grease gun. Pressure exerted by the lubricant tends to lift the plug from its seated position and allow easy rotation. However, the best way of assuring yourself that the valve is operable is to operate it. A frozen or stuck plug valve when you need to open or close it is trouble of the first order.

Needle valves appear quite frequently and should be frequently lapped in to assure efficient operation and control.

Foot valves on pumps can be troublesome and may be difficult to maintain due to their inaccessibility. Most of the trouble will present itself in a loss of suction of your pump due to its losing its prime. Most foot valves are of a flap valve type with a metal to metal seat or a metal to composition seat, with the flapper hinged at one point. This hinge, due to sand, grit or sediment, may stick with the valve in an open position. This can be serious if you do not have some auxiliary priming system available or a means of letting main water back to the pump. If this is the case, the foot valve must be removed, the hinge section freed and cleaned and probably the seat adjusted or dressed. A stuck foot valve may sometimes be freed by bumping it with the pump. That is, starting and stopping it rapidly so as the weight of the water tends to jar the valve loose.

## AUXILIARY DRIVES

Many of the plants have auxiliary drives either in the form of a diesel engine or gasoline engine driving a unit such as a compressor, pump or alternator which may either be manually or automatically started in case of power failure or as a means of reducing peak electrical demands or as a fire pump for the system. Manufacturers' instructions and their maintenance manuals should be carefully followed in maintaining these units. In general, however, they should be started regularly and operated until normal operating conditions such as temperature, oil pressure etc. are reached. If the unit is equipped with a starter, the battery should be regularly inspected and checked. The battery may have its own trickle charger attached to maintain the battery charge. Special care should be exercised with this unit. A too high charging rate may burn out your battery making the engine difficult to start. We have found it expedient to discard or disconnect the charger in some of our plants and rely only on weekly or semi-weekly checks of the engine to maintain the battery charge. If the engine and battery are in good condition the battery will recharge itself

during operation and hold the charge until required again. In isolated unheated pump houses attention must be given to the provision of anti-freeze in radiator cooled auxiliaries. If right angle drives are used attention should be given to the reverse spin stops; in some instances grease has been used to hold drop pins or balls when assembling the unit, the pins will often stick and the purpose of the devices is defeated. Clutch and universal assemblies must be regularly inspected and serviced. A grabbing clutch can cause a great deal of damage and, if it does not release, further damage can be done to the auxiliary drive. On automatically started equipment a time delay device should be incorporated in the control circuits to prevent the unit starting too soon. The delay in starting should be of the order of 15 to 30 seconds otherwise your engine may be trying to start at the slightest power flicker.

## PUMPS

I am not going into all the ramifications of pump maintenance as this has either been covered by others but it is necessary to point out the importance of correct and accurate pump and drive alignment. Alignment of units should be checked frequently. This relatively simple procedure will in many cases point out the possibility of corrective maintenance on bearings, shafts and seals on the unit itself. You have probably all noticed that some pumps seem to operate better under certain temperature conditions. This can be attributed to pump alignment. Pumping units are usually set up to very close tolerances and these settings may change due to the physical temperature of the pump. Casings, bed plates and shafts will all vary slightly in size due to temperature, inside temperature, outside temperature and temperature of the water. A sudden drop in water temperature may seriously affect alignment tolerances.

## MICROTRAINERS

A microstrainer is essentially an open drum covered with a very fine stainless steel fabric rotating under controlled conditions and with a means of constantly washing the fabric covering. In the water works field it is primarily used as a raw water conditioning device but in some cases has been used with chlorination as the only treatment. They are primarily used for algae control and they cannot be relied upon for turbidity removal. There are not many in use but more and more installations are being made. Relatively few of you have them but the maintenance problems associated with them may be of interest. These problems are many and the operator having one or several must maintain constant supervisory control over them. In operation, raw water passes through the fabric from the inside to outside, as the strainer is rotated, a

constant washing action is provided through a series of fan shaped sprays on the outside, washing algae or other small solids into a trough located in the interior of the unit and so to waste.

The unit itself must be installed in strict compliance with the manufacturers' specifications otherwise abnormal head differentials may be set up between the interior and the exterior of the strainer and the fabric may become strained and overstressed resulting in pin holes and eventual tearing. Operating speeds and wash water jet pressures should be varied as per manufacturers' instructions.

In spite of the care and supervision exercised on these units, certain conditions of raw water may cause operating troubles and possible blinding of the fabric. This normally results from a slime condition coating the fabric. "Shock" chlorination cleaning is then used. This treatment consists of lowering the water level in the strainer chambers to about 4" and the spraying of the fabric after the jets have been shut off with 1 gallon of 12 1/2% Sodium hypochlorite. The drum is then rotated at slow speed for about 15 minutes and the jet wash applied at full pressure and the chambers drained to waste. Under no conditions are bleaching powders to be used as these may block the fabric apertures.

In all respects a microstrainer should be treated as a delicate instrument, manufacturers' instructions relating to installation, lubrication, cleaning, starting, stopping, and operation, must be followed exactly, slam-bang; ham handed operating practices must be forgotten and care and vigilance exercised.

REMOVAL OF BACTERIA FROM WATER

by

L. T. Vlassoff

Bacteriologist - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961



# REMOVAL OF BACTERIA FROM WATER

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## INTRODUCTION

The Bacteriological section of the basic course given previously, dealt with the nature of bacteria, the danger and source of disease organisms in water, the relationship between disease organisms and coliform bacteria, with a brief summary and laboratory demonstration of the methods used in examining water for the presence of this indicator group, and a brief introduction to some of the nuisance organisms. Coliform bacteria were established as the group of micro-organisms that indicated the presence or absence of sewage in water. It was noted that only by conducting sensitive bacterial (and not chemical) determinations, could sewage pollution at very low levels be detected. The point was also made that the identification of any member of the coliform group of bacteria with drinking water, indicated an unsafe water supply.

An opportunity to discuss coliforms, Escherichia coli, disease organisms, nuisance organisms and other aspects of bacterial interference, will be given during the laboratory period scheduled later during this course. It is hoped that individual problems of a microbial nature will be brought to light at that time and whether they deal with any of the material in today's discussions or in that during the basic course or any other problem, they will be welcomed.

This section of the lecture will deal with the removal of bacteria from water. In order to better understand the elimination of a microbial population, some factors influencing its existence therein must first be considered.

It is said that water requires treatment, in order that it may be rendered safe for consumers and to ensure that it is wholesome, sparkling and clear. To fulfill this obligation, any treatment process is required to remove suspended and dissolved mineral or organic material, or neutralize substances of a poisonous nature and to kill disease and nuisance producing organisms that may be present from time to time. Before a suitable source of water can be decided upon and the type of treatment that it may require can be determined, factors influencing these criteria must first be taken into consideration.

Basic to understanding the problems involved are the following points: In some natural waters, the microbial content is roughly proportional to the amount of organic matter present



with a larger variety of organisms present in clean waters. This relationship between organic matter and an increase in population, is of great importance, particularly where constant larger quantities of dissolved organic matter are involved. In this case, nutrients may become available to bacteria existing in the water mains following treatment, causing rapid microbial growth which may eventually become a nuisance. Polluted waters generally support larger populations of fewer varieties of organisms. An example that may be cited, is the large numbers of coliforms and other intestinal bacteria present in the event of fecal pollution.

### Flowing Water

Flowing water in streams will tend to purify itself more rapidly than quiescent water. The organic matter therein in the presence of oxygen entering the water by surface aeration, riffles and as a by-product of the growth of algae, is rapidly degraded by the micro-organisms. The number and species of organisms present will depend upon the manner and type of waste discharged upstream. If the waste is chlorinated, the microbial population will be reduced by 70% to 99%, and factors such as dilution will have to be relied upon, to reduce the toxic effects of chlorine before degradation of organic matter in the natural purification cycle can take place. In some cases the polluted zone will be extended further down the river, until the microbial population recovers (aftergrowths) and degradation is accomplished. Excessive doses of disinfectant (chlorine, etc.) in waste treatment may be effective in avoiding septic conditions in a populated area (for example) but it must be realized that the zone of heavy organic pollution is merely pushed further downstream by this practice.

Temperature and pH are two other major factors affecting the zone of pollution in a stream and, therefore, require consideration. Lower temperatures will slow microbial activity causing extension of the polluted zone. A high pH (the alkaline range) will restrict bacterial growth with the result that degradation of organics will become largely a fungal process. Water containing minute bacterial bodies will be more easily filtered than that containing fungal filaments. These factors are of importance in arriving at the location of a suitable intake, if efficient, safe and economical water treatment is to be achieved.

Control of the temperature, pH and other factors that may effect the amount of organic material and eventually the microbial population, is not always possible. However, by controlling pollution around the catchment area, by excluding humans and larger animals, significant reduction in the amount of organic material reaching a stream as well as a gross reduction in coliform content may be had. Some organic material will pass into the water from the land, vegetation and from small animals and birds, but it has been shown that the water will very likely have low coliform numbers and substantial reductions in the quantity of organic material will be observed.

## Impounded and Still Water

Quiescent waters are usually much slower in stabilizing the organic compounds therein, and the factors responsible for this slower rate of degradation are poor aeration, temperature variation, and sedimentation. Aeration in this case depends upon wave action, convection currents, wind and algae. In shallow ponds the growth of algae may play a greater role in the aeration of water, however, as the depth of the water increases, the effect of algae on aeration will generally decrease substantially. Seasonal temperatures will have a greater effect on a standing body of water. Each season a complete turnover of organisms capable of degrading organic material, will be made and during this turnover, the rate of degradation will be interrupted awaiting the development of a new flora. Sedimentation of suspended particles will also carry down part of the micro-flora. The organic material in clumps and suspended microbial bodies may both be taken away from the zone rich in oxygen thereby further slowing down the degradation progress.

Numerous bacterial quality objectives have been established by various agencies for waters used as sources for potential potable supplies. Since many of these have been influenced by the United States Public Health Service recommendations, these should be stated here.

"For waters acceptable for treatment by conventional rapid-sand filtration with continuous postchlorination, the monthly average density of coliform organisms should not exceed 5,000 per 100 ml; and not more than 20% of all samples examined during any month should exceed that density. The use of auxiliary treatment--prechlorination, pre-sedimentation, or the equivalent--does not permit an increase in the monthly average density of coliform organisms, but does permit more than 20% of these samples examined in any single month to exceed 5,000 per 100 ml., provided not more than 5% exceeds 20,000 per 100 ml."

Walton in 1956 reported that for several years water treatment plants have been producing acceptable drinking water from natural waters having coliform counts exceeding these recommendations. As a result of these and new techniques, revision of the objectives is presently under way.

The need for such an elaborate standard has not been felt necessary in Ontario: a coliform count of 2,400 per 100 mls. which is a universally accepted bathing water standard, had been chosen for this purpose.

In order to fully understand these objectives, the efficiency of removal of micro-organisms from water by the conventional methods of sedimentation, flocculation, filtration and chlorination should be discussed.

## Sedimentation

Sedimentation reduces the bacterial count of water from 25 to 75% under normal conditions. The efficiency may increase depending upon the length of time that the water remains standing.

## Floculation

The chemistry involved in floculation has been dealt with by others, and only the effects of various flocs on the removal of micro-organisms will be discussed in this section.

The critical time for the formation of the coagulant micro-organism complex in relation to the removal of viruses and E. Coli cells by practical doses of alum at 25°C is thought to be confined to the first few minutes after the addition of the coagulant. Under laboratory conditions the removal of Coxsackie virus by 25 p.p.m. alum in raw Ohio River water having turbidity readings under 260 p.p.m. was 95 to 99% at 5 to 15°C and 25°C respectively. By reducing the amount of alum to 15 p.p.m., 95.7% removal at 25°C was accomplished. However, under the same conditions, about 99% of the E. Coli cells and the total bacteria were removed. Removal of bacteria therefore, by floculation is far more efficient than the removal of viruses. It must be remembered however, that large populations of bacteria are being dealt with and a 99% removal when applied to the number of bacteria present in the untreated water may mean that 10's and sometimes 100's of thousands escape this treatment.

The virus removal efficiency when ferric chloride is used as a flocculant is comparable to that of alum, but the bacterial removal efficiency is somewhat lower as pointed out in the studies carried out by the U.S. Public Health Service. Calcium and magnesium ions were found to contribute to this lower bacterial removal.

## Filtration

Intermittent rapid sand filters generally remove 90 to 95% of the bacteria while slow sand filtration removed from 95 to 99%. In our laboratory, we have found that some of the smaller filter units, of the type that may be adapted to a water faucet or the type that may be used in pool water filtration, often have the efficiency of slow sand filters. Virus removal figures are not available here and it is assumed that even greater inefficiencies in removal would be apparent.

## Disinfection with Chlorine

Again chlorination in its varied forms and uses has been mentioned by others and the chemistry of chlorination has been explained. It is our intention here merely to bring out some of

the details regarding the effectiveness of chlorination on the removal of vegetative bacteria, bacterial spores, viruses and cysts such as those of Endamoeba histolytica. Some factors already mentioned, include the contact time between chlorine and the micro-organism, the temperature and pH of the water. It seems obvious that the longer the contact time the more effective the disinfection. At lower temperatures and higher pH values, disinfection becomes less effective in most cases.

Under the most favourable conditions, that is, at a pH of 7.0 to 7.6 and a water temperature of 20 to 25°C, almost 100% kills of vegetative bacterial cells can be obtained with combined available chlorine residuals of about 1.2 p.p.m. in 20 minutes. Under similar conditions with free available chlorine, close to 100% kills are obtained with 0.04 to 0.05 p.p.m. residuals in one minute of contact time.

To obtain a comparable kill with the same contact period requires about 25 times as much residual combined as free available chlorine in water is apparent.

Chlorine is not as effective as a sporicidal agent, however. In the alkaline pH range and at normal air temperature (22°C) a 99.999% kill of bacterial spores in 90 minutes requires free available chlorine residuals in the range of 2 to 450 p.p.m. A slightly acid pH range (approximately 6.2) and free available chlorine seems to be the most effective, though satisfactory kills still require a long contact time. At lower temperatures somewhat larger doses are required to produce the same sporicidal effect.

Chlorine as a cysticidal agent increased in effectiveness with an increase in temperature, contact time as well as a lowering of pH. Cysts of E. histolytica for example, will be killed by 5 p.p.m. of free available chlorine at 22 to 25°C at pH's of 8 or less in 30 minutes.

With respect to the effectiveness of chlorine on viruses, it has been stated that from 7 to 46 times as much free available chlorine must be used to obtain 100% kills. The different types of viruses, the amount of OM present and other minor factors are the cause of this wide variation.

In conclusion, the suitability of the source of water should be considered in the light of the amount of organic matter present and the character of any wastes it may contain. Physical agents such as sedimentation, flocculation and filtration at best, only reduce bacterial numbers. Chemical disinfection for waters requiring any physical treatment, must be relied upon to remove vegetative bacteria and reduce the numbers of the remaining micro-flow.

# NUISANCE ORGANISMS

by

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An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961



## NUISANCE ORGANISMS

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### INTRODUCTION

The nuisance organism group is comprised of bacteria and related organisms, excluding algae, that are not normally thought of as public health hazards, but are important to the water works operator because of the problems they can cause in the wells and reservoirs, in the distribution system and/or in the homes of consumers. Not all operators have had to cope with these problems, but given the proper conditions, any plant or distribution system may become infested.

The effects of the presence of these organisms may be seen in the following ways: Taste and odour problems, mechanical blockage of filter screens and conduits and discolouration of the water which may in turn cause the staining of fixtures, or the staining of clothes which may be washed in the water.

The nuisance organisms may be placed into four groups:

1. Iron Bacteria
2. Sulphate Reducing Bacteria
3. Actinomycetes
4. Total Bacterial Population.

Of the four groups, one and two are probably the most common nuisances encountered.

#### 1. THE IRON BACTERIA

This is a group of organisms capable of oxidizing the dissolved ferrous iron in the water or produce ferric hydroxide. Some workers feel that from the process of oxidation, the bacterial cells obtain energy for growth and reproduction. In other words, the ferrous iron is the food on which the bacteria depend for life and survival. Ferric hydroxide constitutes the waste products from the metabolism of this particular type of bacteria. Others studying these organisms feel the precipitation of iron is merely a side reaction, not essential to the life of the bacteria. To the plant operator, however, just the fact that the reaction takes place is of concern. The following equation may be used to illustrate the reaction: Dissolved ferrous iron + iron bacteria  $\longrightarrow$  precipitated ferric hydroxide ( $\text{Fe}(\text{OH})_3$ ) + energy for bacterial metabolism.

The identification and classification of the iron bacteria depends on their type of growth and methods of deposition of the ferric hydroxide. These can be seen under a microscope.

The environmental and nutritional requirements for growth vary widely. Growths have been found in springs with temperatures as low as 1°C, as well as water pipes and mineral springs with temperatures as high as 32°C (87.6°F.). Light appears to have no effect as growths have been observed in exposed, sunny locations as well as in pipes. Although dissolved iron is a requirement for growth, the iron bacteria are capable of growing in waters containing 0.1 to 30 p.p.m. However, with low iron concentrations, it is probable that for development of the iron bacteria, the water must be moving to continually replenish the supply of iron. Dissolved iron may be present in the raw water supply or it may be dissolved from iron pipes by an acid pH. The low pH may be naturally present because of the solution of large amounts of dissolved CO<sub>2</sub> or it may be produced by the action of the other bacteria in the water on sulphates or organic matter present. The optimum pH range for iron bacteria is 5.5 to 7.8.

The problems caused by this group of organisms are twofold. Firstly, the growth of the organism and subsequent accumulation of slime in the pipelines may mechanically impede the flow of water, resulting in a reduction in the capacity of the mains and an increase in the pumping pressures required. Secondly, the slime accumulations may periodically break loose. They may subsequently remain in the lines and be broken down to produce tastes in the water or they may be passed through the lines to the consumer as chunks or strands of reddish-brown gelatinous material. These may cause the staining of clothes washed in the water or make the water undesirable for drinking purposes.

These bacteria are not easily grown in the laboratory and the control methods established thus far are not 100% satisfactory.

The following measures have been recommended for the control and elimination of iron bacteria:

- 1) Iron Removal

The methods of iron removal have been covered in a previous paper. Its usefulness as a control of the growth of iron bacteria is questionable because, as previously stated, a very low level of iron--even less than the accepted standard--is sufficient to support growth of the organisms.



## 2) Copper Sulphate Treatment

The amount of copper sulphate--a salt often used to control algal growth--required for control of iron bacteria is toxic to humans and so is of little use where municipal supplies are concerned.

## 3) Soda-Lime Treatment

This treatment has been successfully used to control growths of some iron bacteria by raising the pH of the water to a slightly alkaline point. This inhibits the growth of the organism, but may cause other chemical problems, such as the deposition of calcium carbonate.

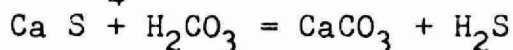
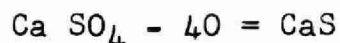
## 4) Chlorination

Simple chlorination has not been highly successful in controlling growths, but the maintenance of a residual of 1 p.p.m. chlorine, following superchlorination may be successful. The success depends on the degree of penetration of the chlorine into dead ends, etc., and the amount of growth initially present. In any elimination procedure, complaints may be received as the bacteria die off and decompose, but proper flushing following treatment may diminish this possibility.

## 5) The least expensive and least troublesome method still appears to be good housekeeping and a regular program of flushing will lessen the problem in most cases.

# 2. THE SULPHATE REDUCING BACTERIA

The sulphate reducing group of organisms are, as their name implies, active on the sulphates present in waters. As part of their metabolism, they reduce the sulphates to produce hydrogen sulphide ( $H_2S$ ). With calcium sulphate, the reaction takes place according to the following reactions:



The release of the  $H_2S$  into the water results in an off taste along with the very objectionable odour of rotten eggs. In one instance in California, the amount of gas released was so great that it caused the white lead paint in a bathroom to turn dingy brown by chemically combining with the lead of the paint to produce lead sulphide.

The sulphate reducing group obtains its oxygen and energy for growth from the reduction of sulphates and, therefore, flourishes in situations where oxygen is not present. These conditions may be found in municipal distribution systems in such places as dead ends and simulated dead ends where quantities of water may sit for some time before they move. The gas produced diffuses out from the dead ends and is released into the water consumed.

In one instance, the odour was more noticeable in the hot water than the cold. Probably the increase in the temperature of the water resulted in the gas being given off. Subsequent flushing of the hot water tanks removed the nuisance.

The fact that this water was being chlorinated shows that chlorine may not seriously affect the bacteria because of the difficulty of maintaining a chlorine residual in the dead ends which may have a high chlorine demand. It also shows that a regular flushing program may be the best method of eliminating this situation.

### 3. ACTINOMYCETES

This group of organisms is closely related to bacteria, both physically and biochemically. In water, they may cause earthy, fishy, grassy, hay-like and potato-bin like tastes and odours.

Winter temperatures are usually low enough to inhibit their development to the point where they become nuisances. However, in the remainder of the year, particularly late summer and early fall, their effects may be encountered. One author suggests that this is because their spores or "seeds" germinate in the spring. Because of the rise in temperature, they increase in numbers through early summer and finally reach the point where they become nuisances.

The habitat of this group is generally soil and bottom muds, so they are more often encountered in waters from surface supplies and those impounded in reservoirs before distribution. However, in an isolated case, they have been known to become a problem in a well with a wooden casing.

In one instance in California, the actinomycetes were controlled by maintaining a constant copper residual of 0.1 p.p.m. in the water using copper sulphate as the source of copper. The value of this procedure has been questioned by another author who suggests that treatment

to remove tastes and odours should be carried out in the purification plant rather than attempting the relatively expensive eradication of the source of the problem from the supply. The situation and construction of the reservoir to limit both shallow water and pollution can do much to eliminate the actinomycetes by reducing their nutrient supply.

The spores of the organisms, being the same size or even smaller than bacteria, may easily pass through filters and thereby gain access to the distribution system. If the water in the main reaches the appropriate temperature--60 to 65°F--tastes and odours may emanate from the growth in the mains. Bi-products produced by the actinomycetes may combine with chlorine and the taste is intensified much in the manner that chlorine and phenol react. Eradication of actinomycetes in water mains has been accomplished by regular, periodic treatment with approximately 8 p.p.m. chlorine dioxide.

#### 4. TOTAL BACTERIAL POPULATION

The total bacterial population in a municipal water supply becomes of concern when it becomes exceedingly high. Normally, chlorination keeps the total population quite low and thus significant increase in the total population indicates that organic matter may have gained entrance to the supply and trouble may occur.

A taste and odour problem may develop as the mass of cells begins to decompose. The problem may disappear quite quickly if it is a case of isolated contamination, or it may persist and/or increase if contamination is continuous. The duration of the problem cannot be predicted unless the cause of the trouble is discovered.

Once again the maintenance of the recommended chlorine residual should take care of the problem. However, if it persists, the problem may be mechanically controlled by flushing.

WATER DISTRIBUTION SYSTEM MAINTENANCE

by

G. Kay

District Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

# WATER DISTRIBUTION SYSTEM MAINTENANCE

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## INTRODUCTION

I assume that all of you have attended the Basic Water Works Course, and therefore have retained Mr. Caverly's lecture of the same title. Later today you are to have a lecture and demonstration on piping and connections together with lectures on meter maintenance, leak detection and pipe thawing. Therefore, I shall be attempting to avoid any undue duplication of presentations.

## GENERAL

The distribution system has been described variously as consisting of the distribution mains, valves, hydrants, service connections, meters, booster pumping stations, and distribution storage facilities.

Consumer dependence on an uninterrupted public water supply has grown almost beyond belief within the past two decades, and adequate maintenance will be required to keep the system in a condition suitable to retain good relations with the consumer public. The person responsible for the functioning of these units, therefore, must be familiar with the means and methods to maintain them properly.

## MAINTENANCE PROGRAM

The maintenance program then consists of two phases: anticipating normal depreciation by routine checks and preventative procedures, and being organized to handle a distribution system crisis.

The best maintenance aid, of course, is a proper initial installation. For instance, if all watermains were laid by hand on a shaped bottom of undisturbed soil, there probably would be fewer breaks and inconveniences. However, with increased labour costs, machine digging predominates and this does not lend itself economically to a shaped bottom. Rather, loose material is added to the bottom of the trench and it is intended that this is compacted under and around the pipe to provide an adequate bearing medium.

## DISTRIBUTION MAINS

Of necessity, the maintenance staff is concerned with

quickly repairing any subsequent leaks or breaks in order to maintain service.

I think that it is also advantageous to have some knowledge of the apparent causes of main breaks when repairing these.

The cause of pipeline breaks is a continuing assessment and one on which all the principals are not agreed. Often, this has been aggravated by the lack of proper assessments of the initial conditions found at the repair excavation. It would appear, however, that in frost areas, the greater number of breakages result from a cumulation of forces and the larger percentage occur during the winter months, in the early hours of the morning, when main pressure is usually at its greatest value.

In surface water supply systems the temperature of the water may vary from over 70°F. in the summer to 32°F. during the winter. The temperature of ground water supplies does not vary so appreciably. At the time in the year that the water experiences its most rapid drop in temperature, it causes the water mains to attempt to appreciably decrease their individual lengths. If the joints are rigid, such as those bell-and-spigot joints where sulphur compounds were used, the pipe is restrained from this shrinkage and is held in tension. This is not sufficient in itself to cause fracture, but with an assist from corrosion-thinned walls, beam action from a point of pressure such as a rock in the bedding, cantilever action from frost or voids and metal fatigue from repeated flexure due to vibration, etc., fracture may result. If the frost penetrates to the main, vibration from traffic loads can be transmitted directly thereto. Disturbances due to other underground construction as well as water hammer, also can induce fracture. In small pipe sizes, the beam or cantilever stress usually predominates and results in a circumferential break. Larger sizes usually fail due to ring stresses and fracture longitudinally.

The circumferential break can sometimes be repaired with split repair sleeves without dewatering the main. There is a multitude of repair sleeves and clamps for this purpose on the market which were originally considered only temporary measures but which have now proved themselves to be worthy of being considered as permanent repairs.

The longitudinal break, depending upon its severity, may necessitate dewatering the main and the insertion of a plain end section.

The prime intent is to excavate and repair the main as soon as possible, and then restore it, using proper methods to avoid a future fracture there. The soil should be well compacted under and around the pipe in the proximity of the repair. Granular material would be desirable here while a further preference would be to use 3/8" crushed stone, since it is less effected by water in the trench.



As I have stated above, the rigid joint appears to have been one of the worst offenders in surface water supply system breaks in frost areas, and the advent of rubber joints for water main construction should tend to reduce the percentage of breaks. It is important with these joints, however, to preserve adequate blocking or strapping for the full thrust that is to be developed on any bend, change of direction or end of the line.

Active interest is being shown in the use of ductile iron for pipe in water distribution system. Possibly the advent of standards for pipe of this material will accelerate its usage.

Some poured bell-and-spigot jointing materials have tended to expand over the years to rupture the bells. These can be repaired with bell repair clamps or by cutting in a piece of plain end pipe. When this trouble can be anticipated it may be preferable, particularly if paving is imminent, to replace these known trouble joints even prior to their rupture.

#### DISTRIBUTION VALVES

The number and location of fully operative valves in the system will predicate to a great deal, the degree of inconvenience that will be suffered by the customer at times of repairs. It would be difficult to find a water distribution system where a surplus of valves had been installed. Valve man-holes or vaults on the mains are desirable, but financial considerations usually predicate their use only on those valves in excess of 10" in diameter, or in special locations.

Little can be done to maintain the buried valve without excavation, except for operating it, preferably annually. But even this alone can often prevent it from becoming inoperative, as well as confirming its operating details. Since most of these valves are of the gate type and constructed of dissimilar materials, galvanic corrosion can take place at the moving faces. Without operation of the valve, the by-products of this corrosion will ultimately seize these faces and render the valve inoperative.

It is desirable to have all main valves open with the valve stem turning in the same direction. Where a valve opens in the opposite direction, to the majority, some indication at the site is sometimes given, such as painting the underside of the valve box top a bright colour. Power tools for valve operation can assist in any major maintenance programme.

The valve stem is attacked by corrosion and without operation will ultimately seize and can result in a broken stem. The packing can be softened by the application of kerosene or other lubricant, and the number of turns, right or left to open, should be checked each time to avoid undue torque being applied.



Blockages can sometimes be flushed from the valve by partially closing the valve, closing an adjacent main valve, and opening a hydrant between these two. Unauthorized personnel should be prevented from the operation of the valves.

A common problem has been the inability to engage the key due to stones having been placed in the valve box by children. Lock-type tops have been developed, and I have one of these for your inspection.

Valves in vaults are more easily maintained, and in some instances, can be partially rebuilt without removal. Gland leakage during operation is not considered serious, but continual leaking requires attention. Mr. Perry has already given you an extensive valve maintenance presentation, and I merely wish to refer you to his lecture.

Inspections are required of all street improvement projects to ensure that all valve boxes and vault tops are in position and properly graded. Stakes are sometimes of value to indicate the original position of known valves, and their boxes. This is an opportune time also to install new packing or additional valves before paving is completed.

It is also important to retain and uncover if necessary, all these units after any paving or resurfacing has been completed.

## MAIN CLEANING

One of the most important maintenance operations is that of maintaining the carrying capacity of the mains. Corrosion and incrustations or slime formation in waterlines often causes a serious loss in main carrying capacity and pressure. Cleaning, or cleaning and lining, are the maintenance operations to be performed, as an alternative to laying new mains.

The severity of internal corrosion can be continually assessed by examination of the coupons removed during tapping valve-and-sleeve installations and also by observing the pipe removed from break locations.

A chain-head auger and a scraper type cleaning tool are usually used.

The chain head auger is essentially a steel rod which has short lengths of chain attached to it. On the end of each chain is a heavy metal weight. The steel rod is rotated at speeds between 300 and 1000 r.p.m.

The scraper type tool consists of several discs strung on a flexible rod, and anchored front and back. Extending from

the circular edge of the discs are rectangular steel scrapers bent at the ends. In some instances this tool is allowed free travel, propelled by hydraulic action. However, the chance of subsequent blockages necessitating excavation sometimes suggests that this tool is better controlled when pulled through the pipe sections by a power winch.

Pits are dug at both ends of the pipe section to be cleaned, and the desired lengths of pipe are cut out with a power saw. Pumps are commonly used to remove the water accumulating in the downstream pit.

Pipe cleaning is usually followed by continuous chemical treatment of the water supply by glassy hexametaphosphates (Calgon), or more commonly by installing a cement lining in the pipe. In the small sizes, this is done by placing sufficient cement mortar in the pipe line, so that a following mandrel will apply the required thickness when it is pulled through the pipe, behind this mortar.

In the larger pipes, an operator in the pipe directs a machine which sprays a concrete mixture on the walls, and rotating trowels smooths it to a proper value.

I have acquired a short film on water main cleaning and I would propose to show it to you now.

#### HYDRANTS

In most water systems, hydrants are the only parts of the system which are in evidence to the public and a neat appearance will provide public admiration. This requires proper painting maintenance and reflecting paints appear to be gaining favour, with indications given on the hydrant also, of the main's size or capacity. This painting is commonly performed approximately every two years.

Whereas it would be desirable to use the hydrant for only fire fighting purposes, other demands are often made of it and it is usual to allow the judicious use thereof, upon acquiring a permit for a nominal sum. Sometimes an added flat rate is applied or a temporary water meter is installed. To avoid damage to the hydrant by improper and repetitive opening and closing, it is desirable to install an auxiliary valve on one of the hose nozzles and have authorized personnel using the proper wrench open and close the hydrant only at the start and end of the required period of use.

Wherever possible, this water should be drawn from dead end hydrants to assist the flushing thereof.

It is desirable to have gate valves located on all branch connections to hydrants, but financial situations may preclude these in the initial installation. Although most hydrants are now designed to allow replacement from the surface in the incidence of damage from vehicles, etc., the flow to the hydrant usually must be cut off later to allow examination of the main valve components. A program of auxiliary gate valve installations can be inaugurated, particularly using equipment allowing valve installation under pressure. Valving hydrant branches in all industrial and commercial areas, as well as on mains over 10" in diameter, should be a first consideration.

Hydrants always should be set on a block on undisturbed ground, adequately braced, and, if self-draining, should be provided with a drainage pit of 3/4" crushed stone approximately 2' in diameter, 2' deep, and to about 6" above the waste opening, with a building paper cover. Other equivalent pits also would be acceptable.

In sewered areas, the sewer trenches act as drains and the water table is usually low enough to allow the hydrant drain holes to operate correctly, particularly if adequate gravel or crushed stone has been placed around the hydrant. In non-absorptive soil or where the water table is high, protection must be taken to avoid freezing of the hydrant and thus rendering it unavailable for fire fighting purposes.

Connections from the drill holes or drainage pits to sewers usually is not acceptable since this may be considered to be a cross connection.

In areas where poor drainage conditions persist, there appears to be merit in plugging these holes and relying on adequate pumping of the hydrants. This work is facilitated by the exhaust powered hydrant pump which the Township of Etobicoke was kind enough to loan me today, and which you see here. This has previously been illustrated in the November 1959 issue of the Water Works Digest, and appears to have been first utilized by Mr. R. Spark, general foreman of the Welland Board of Water Commissioners.

If the drain holes are not plugged on these problem hydrants, an antifreeze compound, but preferably not salt due to its corrosive tendencies, is added, together with other insulating procedures. Frequent re-inspections, possibly twice a week depending on frost intensity, are required, particularly since the solutions may become diluted with ground water and have their antifreeze properties reduced.

Steam generators usually are used to thaw hydrants and are often sent out on all winter fire calls. When freezing below the valve takes place, the hydrant should be thawed daily.

Some flushing may help to keep the hydrant and the branch line from freezing. The fire department should be advised of any in-operative hydrants and also preferably these should be so indicated on the site.

With the advent of decreased price differentials, the trend appears to be towards the increased use of the more efficient and more easily maintained compression-type hydrant.

Hydrants should be checked twice to four times a year, preferably in the spring and fall and also after each use. Naturally, however, the problem hydrants will become known and should be accorded the more frequent inspections, probably daily, during winter months. Points to check are the stuffing box (unless O rings are used), valve, valve seat, barrel (for cracks), opening of the drain port (if not purposely plugged), threads, geared opening mechanism and gaskets - the methods used, depending upon the make of the hydrant. It should be remembered that hose nozzle caps should not be replaced immediately in order that the water may drain from the hydrant barrel. The valve should be opened and closed slowly to reduce the occurrence of water hammer. The inspections should also ensure that householders have not built fences or changed lawn grades which now conflict with the operation or frost-resisting ability of the hydrant. The hydrant must be clearly visible at all times and this may necessitate the attaching of poles and metal flags during snow periods in some areas.

## SERVICE CONNECTIONS

Drilling and tapping mains for service connections is required of most water works maintenance forces. This is usually done while the main is under pressure. Care should be taken to provide a sound connection and to avoid damaging the pipe itself. The attaching chain should be well tightened to prevent slippage of the machine and subsequent drill breakage. It is desirable to have the tools sharp and so avoid bruising the pipe to cause hairline cracks. Mueller or corporation threaded corporation stops are preferable, due in part to extra strength at the thread termination.

Then tapping cement, or asbestos-cement mains, drills with tungsten carbide tips will last a good deal longer than the ordinary drill used for cast iron.

Frost action tends to bear on the main and if the connection is rigidly attached rather than with a goose neck, the beam or cantilever forces on the pipe usually result in rupture of the connection.

In most instances, the trend appears to be to use a saddle rather than a branch connection when the required service

is more than one-quarter of the nominal main pipe size. Certainly weakening of the pipe by an improper stop installation is to be avoided and to this end, tapping at 45° to the horizontal is preferable.

Copper is the material most commonly used. If a break occurs between the corporation stop and the curb stop, repairs can be assisted by temporarily freezing the service by means of dry ice or a commercial fire extinguisher. Care should be taken to avoid undue exposure to the CO<sub>2</sub> fumes.

#### BOOSTER PUMPING STATIONS

These will require maintenance similar to that described by Mr. Perry and those others dealing with similar plant matters.

#### METERS

I believe that meters will be discussed to some length in another lecture today.

#### DISTRIBUTION STORAGE

Distribution storage facilities consist of several types, but I shall mention here just elevated steel tanks and standpipes.

Generally, the life span of these is limited only by damage due to corrosion of the tank plates and the supporting tower, if any. The cleaning and painting of the inside and outside of these tanks as necessary, is the most common and best protection. The tanks should be drained and inspected in the spring, preferably once a year, and not exceeding 2-3 years. Periodically an unbiased report should be obtained of the total maintenance work required, such as sandblasting, welding, etc. Since the work on these units is rather hazardous, it is usually performed by a reliable contractor experienced in this type of work.

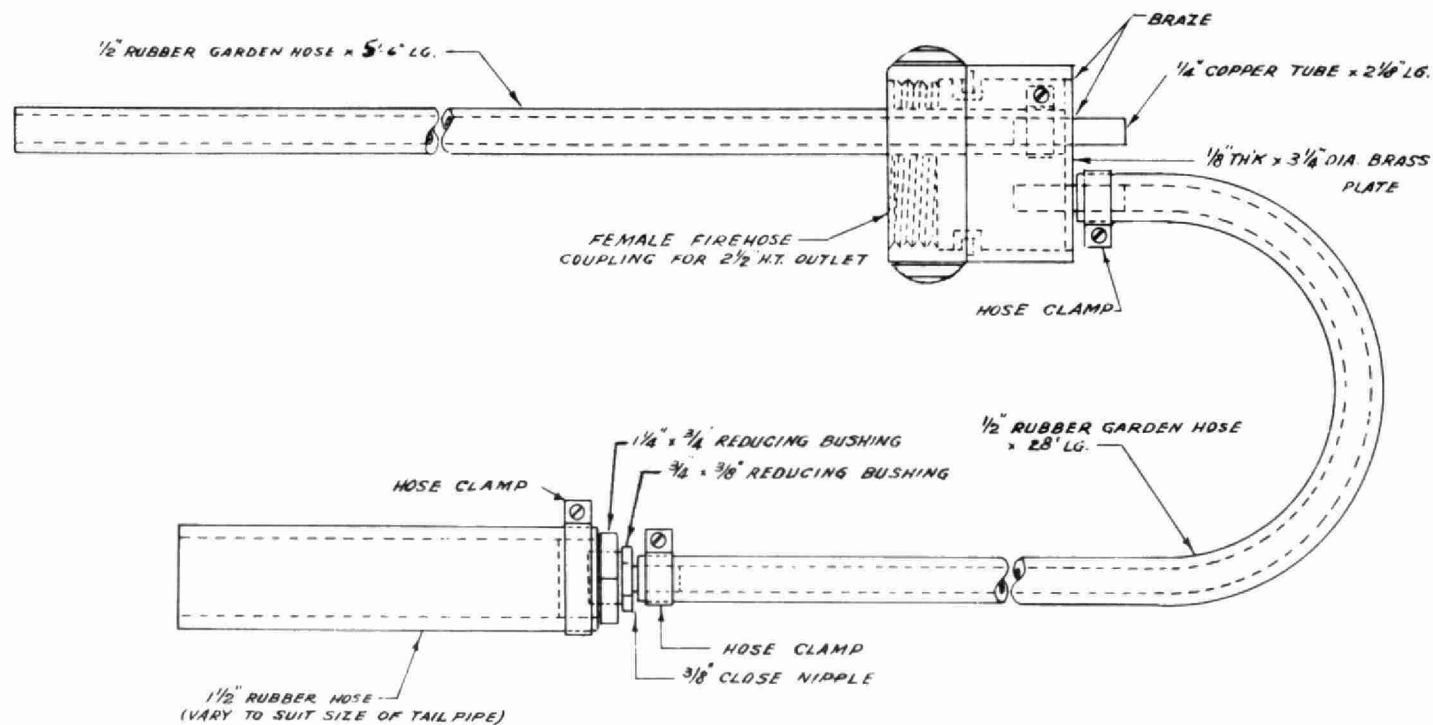
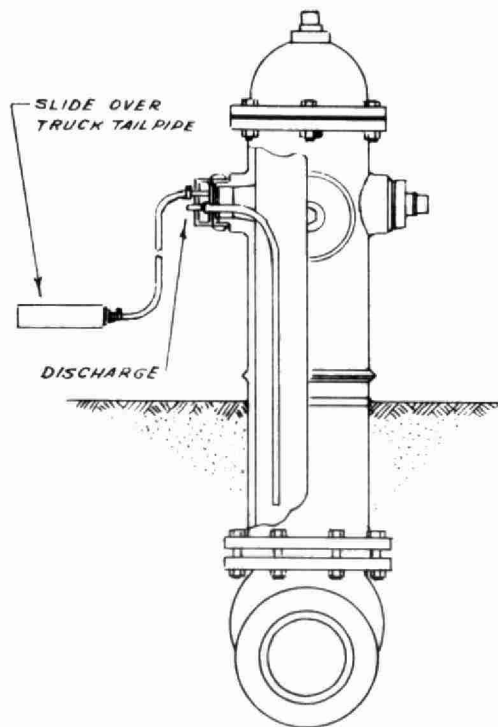
It should be noted that adequate ventilation should be provided while men are painting inside the tank. These men should be given a physical examination prior to the commencement of the work, and the tank should be sterilized and drained to waste prior to being returned to service.

The outside of the tank and its supports should be inspected for possible structural damage also after every serious storm.

SUMMARY

Time is becoming an ever important factor in the repair and restoration of service disrupted due to main pipe breaks. Two-way radios, standby personnel, and closer valve spacing will probably be required of the maintenance department. With increased labour costs a greater number of expensive labour-saving machinery should now be considered.

Considerate investigations of all consumers complaints will be required to maintain good public relations between the maintenance department and the consumer, which is one of the prime aims and requisites of any water works department.



EXHAUST POWERED HYDRANT PUMP



LEAK DETECTION AND PIPE THAWING

by

W. A. Steggles

District Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

## LEAK DETECTION AND PIPE THAWING

W. A. Steggles

District Engineer - OWRC

### LEAK DETECTION

Water system leakage in the USA has been estimated to cost \$50 million annually in operating costs.

Since the water works industry is engaged in the production of a commodity which costs dollars to produce, it like other productive industries must exercise economy throughout the various levels of the enterprise. As no water distribution system is practically leakage free - even water mains laid with the utmost care and under the best construction conditions will leak - some loss of water via leakage must be expected. The AWWA suggest 250 gallons per 24 hr. per in. diameter of pipe per mile as allowable loss by leakage in pipelines. Generally, 10 to 15 per cent of the total water produced in a municipal system is accepted as inevitable loss from leakage. This applies to a well managed system and may be reduced considerably through leak detection and conservation.

Leakage is part of that category of the municipal water budget which has been labelled "Unaccounted-for Water".

Unaccounted-for water may be defined as the difference between the metered water production at the source of supply, and the total quantity recorded by the service meters. Adjustments must be made for the non-metered water consumed which includes:

- flat rate water consumed
- fire protection requirements
- street flushing and other municipal uses
- construction use
- leakage.

Leakage losses occur in three separated areas of any water works system.

1. During the treatment, manufacturing or production process.
2. Throughout the transmission and distribution system.
3. At points where customers use the products.

We will deal principally with the second of these areas -

the detection of leakage in the distribution network.

Control in the first and third areas requires that the utility staff and the public be aware of the significance of leakage; requires frequent maintenance inspections, and effective repair, and general conservation practices.

The most effective control may be had when metering is universal. However, metering necessitates an effective program of meter maintenance.

Finally, the ultimate control of leakage is obtained through regular leak detection surveys throughout suspected high leakage areas.

The magnitude of water loss through leakage is made evident by the following findings of a leakage survey in the City of Ottawa during 1957.

No of Leaks	Description	Leakage g.p.d.
11	Service leaks	141,000
2	Abandoned service leaks	43,000
1	straight break on main	30,000
1	split main leak	350,000
2	hydrant leaks	10,000
1	broken meter leak	30,000
18	Total leakage	604,000

It was estimated that the value of the water lost amounted to \$44,000 annually. These losses were small compared to earlier losses in 1949 which were estimated to amount to \$152,000.

#### METHODS OF LEAK DETECTION

There are many ways in which water main leakage may be evidenced:

- water flowing at the surface of the ground,
- continued wetness in a particular area.
- melted snow in vicinity of leak - the escaping water is relatively warmer.
- increased lushness of vegetation.
- apparently high infiltration into storm and sanitary sewers.
- water in manholes, valve chambers, etc.

## LEAK DETECTION EQUIPMENT

### Types:

1. Mechanical amplifying equipment
2. Electrical amplifying equipment

These devices amplify the sound of water escaping from a line according to the principle of design.

The first device amplifies the mechanical vibration which is transmitted to valves, hydrants, water pipes, etc. The intensity of sound increases in the vicinity of the leak and decreases at points in the system distant from the leak.

The electrical equipment is battery powered. Mechanical vibrations are picked up by the instrument probe and amplified. Visual and audio expressions of the mechanical noise are amplified for interpretation. Once again, increased sound intensity indicates proximity to the source of the noise or leak.

Battery powered equipment is capable of detecting leaks up to one block away.

Isolation of the leaks in a piping system using this equipment are determined in the following manner:

1. Determine the intensity of sound at each hydrant, exposed valve, etc. along the length of water main to be studied.
2. Study in detail the area wherein the sound is the most intense by sounding each immediate service at the point of entry into the house and at the curb stop.
3. Shut-off any suspect services. Open a valve in the house and re-check for a leak. If no sound, the leak is on the customers property.

A main leak may be characterized by sound heard at more than one service. This may be located from the ground surface (the pickup device being placed directly on pavement etc.) or by driving metal rods down to contact the main along its length. In the latter case, the pickup is applied to the metal rods. If the sounding points are spaced at sufficiently close intervals, the leak location may be pinpointed.

## Pitometer Surveys

A more detailed appraisal of unaccounted-for water in larger utilities may be achieved by the pitometer survey. By this procedure the distribution system is divided into districts or sections and the flow input into each isolated zone over a 24 hour period is measured. The losses are appraised by comparing the minimum night flow rate with the average daily flow rate and determining the reasons for excessive or otherwise high flows. Thereafter, detailed leak detection work within the district is required using the aforementioned devices.

## THAWING FROZEN WATER PIPES

### INCIDENCE OF FREEZING PROBLEMS

Frozen water services and mains comprise the major winter operational problem in many cities of Canada and the Northern United States. Freeze-ups occur frequently enough in most municipal water systems in Ontario to require the services of a thawing crew, if not on a full-time basis, at least on a call basis, during winter months. A few municipalities in Southern Ontario experience 300 or more frozen services each winter. Other northern communities consider these figures commonplace.

In the Arctic, special designs are necessary to ensure water circulation. At Fairbanks, Alaska, water is warmed, then pumped at 3 ft./sec. through wood-stave mains and twin copper service lines. This system operates in ground which freezes to depths up to 10 feet in which the soil at 6 feet is as cold as 15 degrees Fahrenheit.

### THEORIES OF HEAT LOSS

Appreciation of the conditions which affect the formation of ice in water requires a brief understanding of the concepts of heat transfer as applied to buried water pipes.

Heat may be defined as the transient or non-permanent form of energy which is transmitted from one body to another when both bodies are not at the same temperature.

In the case of water flowing in a pipeline, if the heat input is less than the heat loss or output, and temperatures of 32 degrees Fahrenheit or less result, then the water changes its form from a liquid to a solid.

## CONCEPTS OF HEAT INPUT AND HEAT LOSSES

### Heat Input

The heat input to a pipeline in a freezing environment is almost entirely due to the temperature level of the flowing water above 32 degrees Fahrenheit. The other source of heat available to prevent the formation of ice is the heat generated by the frictional resistance to the flow of water in a pipeline. This can usually be neglected, but it may be quite significant for small diameter pipes operating at high velocities. It is insignificant at low velocities of flow in large pipes.

### Heat Loss

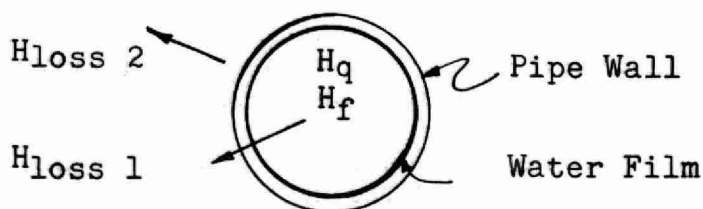
Heat may be lost in several ways; through conduction, convection or by radiation.

Conduction is the process whereby heat is transmitted from one solid particle to an adjacent solid particle - it happens in soils where temperature differences exist between the various soil strata. This process also occurs where temperature differences exist between the water, the water main, and the surrounding soil.

Convection and radiation speak for themselves, the former relating to the movement of heat in the atmosphere, and the latter to the emission of heat rays from a hot centre or source.

Considering the case of an exposed pipeline, heat may be lost through the water film, the pipe wall and by external radiation and convection. (see illustration).

### ILLUSTRATION



### Heat Input

$$\begin{array}{r} H_q \\ H_f \\ \hline H_q + H_f \end{array}$$

### Heat Output

$$\begin{array}{r} H_{loss 1} \text{ (through water} \\ \text{film and pipe} \\ \text{wall)} \\ H_{loss 2} \text{ (convection and} \\ \text{radiation)} \\ \hline H_{loss 1} + H_{loss 2} \end{array}$$

Loss of heat through the thin water film which surrounds the internal circumference of the pipeline is considerable. Conduction or loss of heat through the pipe material itself depends on the conductive characteristics of the material, its thickness and the difference of temperature between the interior and exterior of the pipe.

Radiation from the pipeline exterior depends on the type of material. Convection losses vary with the temperature differences and the size of the pipe. They increase as wind velocities increase.

The problem does not change materially when the pipeline is buried. The sources of heat input remain the same, while the methods of heat loss vary somewhat. Heat transfer through the water film and conduction of heat through the pipe wall remain important factors. Conduction and radiation of heat through the soil are the principle factors involved in the dissipation of heat in the soil.

#### FACTORS WHICH AFFECT SOIL TEMPERATURE

Air Temperature: and other meteorological factors such as: precipitation, sunshine, relative humidity, wind velocity, dewpoint, and barometric pressure.

Surface Cover - snow and vegetation reduce frost penetration and slow its retreat in spring.

- pavement increases frost penetration and accelerates its retreat in the spring.

- dark surface colours increase absorption of solar energy

Soil and Topography - type of soil - a granular soil has a greater frost penetration than a fine-grained cohesive soil.

- Moisture content of soil - density of soil - organic content of soil - concentration of salts - soil structure.

From the above considerations on the flow of heat in soils, it becomes apparent that so long as a favourable balance of heat is maintained in a pipeline, freezing conditions will not develop.

Frozen services are more common than frozen mains. Less water volume and longer periods of no motion are characteristic of services. It is known that insulation of pipes provides considerable protection from freezing. Materials such as wood,



plastic, or possibly glass have been used. Provision of a pipe enclosed within a pipe to provide an air space would provide a solution, albeit an expensive one. The solution - Bury the pipes below the frost line.

The real problem which concerns us here today is "What do You do when Pipes Do Freeze"? Lets leave the problems of pipe design and heat transfer to the designing engineers. Later in this lecture a practical demonstration of pipe thawing will be provided by Mr. J. Dawson, Manager P.U.C., Dunnville.

Frozen water lines require the application of some external source of heat whereby the heat transferred will be sufficient to melt the ice and to permit flow. Many methods have been used:

- digging down to the pipe and building a fire in the trench over it.

- using gasoline torches.

- wrapping pipe in rags and pouring on hot water.

- using steam

- use of electricity.

Other than the use of electricity, these measures involve considerable time, inconvenience and are often messy. Pipes can be split from extreme heat when steam or open fire is used. This is not an attempt to minimize the problems associated with electric resistance thawing. These problems, which are many will be discussed later.

## THEORY OF ELECTRICAL THAWING OF PIPES

Mathametically speaking, the heat produced by electrical current may be expressed by the following equation:

$H = I^2 R t$  In this equation H represents heat in joules.  
I represents current in amperes.  
R represents resistance in ohms.  
t represents time of current flow in seconds.

The temperature increase varies with the current I and the resistance R of the pipe per unit of length. One hundred amps of current will heat 1000 feet of one-inch pipe as quickly as ten feet, but will require one hundred times the voltage.

Simply, the electrical thawing of pipes may be stated thus: The passage of electrical current through a conductor whether it be a wire or pipe line encounters resistance. This resistance creates heat, the intensity of which depends on the characteristics of the conductor.

The following tables give pertinent pipe thawing data.

Metal	*Relative Resistance OHMS per Mil. foot	Approximate Melting Point degrees Fahrenheit
Copper	9.35	1900
Steel	63.00	2600
Wrought Iron	82.80	2800
lead	123.00	625
Cast Iron	684.00	2500

\*Resistance in piece of metal 0.001 in. in diameter and 1 foot long.

#### CONDITIONS AFFECTING THE THAWING OF FROZEN PIPES BY ELECTRICITY

<u>Diam. of pipe in.</u>	<u>Pipe Material</u>	<u>Resistance ohms.</u>	<u>Length ft</u>	<u>Approx* Volts</u>	<u>Amp.</u>	<u>Min. Time</u>	<u>Size Amp B&amp;S.</u>
3/4	Wrought iron	82.80	600	60	250	5	Size of
1	Wrought iron	.....	600	60	300	10	leading
1 1/2	Wrought iron	.....	600	60	350	10	wire to
2	Wrought iron	.....	500	55	400	15	<u>use.</u>
3	Wrought iron	.....	400	50	450	20	0 200
4	Cast Iron	684.00	400	50	500	60	00 225
6	Cast Iron	.....	400	50	600	120	000 275
8	Cast Iron	.....	300	40	600	240	0000 325
3/4	Copper	9.35	400	40	500	30	
1	Copper	.....	400	40	600	60	
1 1/4	Copper	.....	300	35	600	60	
	Steel	63.00					
	Lead	123.00					

\* The lowest possible voltage should be used.

The melting points shown above indicate the danger of melting lead service pipes with high currents. Cast iron heats most readily, while copper, a good conductor heats slowly. Whenever lead goose-necks are used, regardless of the materials used in the remainder of the service, low rates of current should be used to protect the lead.

#### MEANS OF ELECTRICAL THAWING

Either transformers or welding generator sets have been used effectively with currents ranging up to 800 amperes. The use of transformers supplied from hydro primary transmission lines requires the service of hydro personnel to make the primary connections.

Portable welding sets are more flexible, as separate self-contained units. Where copper pipes are involved, generating sets with high amperage ratings should be chosen.

#### THAWING PROCEDURE

1. isolate the frozen section of pipe.
2. include the frozen section in an electrical circuit by connecting cables from the source of energy to the closest convenient points in the piping system.  
  
When Thawing Mains - connections can be made to hydrants, curb service boxes, etc.  
  
For House Service Pipes - connections can be made to exposed pipes in the house and the service stop.
3. Ensure that good electrical connections are made; remove rust scale at the point where the clamp is to be fastened to the pipe. Otherwise arcing may cut holes in the pipe.
4. If a house service is involved, remove the water meter from the circuit to break connection between the service pipe and the house piping.
5. Remove the ground clamp from the water pipe to prevent stray currents getting into the neutral wire and into the house wiring system.
6. Proceed with thawing.

Removal of the meter alone or disconnection of the ground clamp alone is not sufficient assurance that current will not be

fed back into the house wiring circuits. Underground contact of metal pipes or some other chance circuit may occur.

#### SOME DO'S AND DONT'S

1. Use least current possible to accomplish job.

Do not hurry by using high currents. The lower the voltage, the less chance of injury to persons and property including piping appurtenances.

2. Avoid connections which might waste current and prolong the thawing job. Use only generator sets equipped with meters in order to determine the exact amount of current used. If the ammeter does not indicate a current flow, this may be caused by:

1. Poor connections or bad joints in pipe.
2. connections that have been made to different pipe systems.

Make sure the frozen length of pipe is included in the circuit.

3. Avoid possibility of shorts or grounds. Current might be fed back through gas services via the water heater. No gas pipes, furnace support wires, etc., should be in contact with pipe being thawed. Radio ground wiring should be detached. Lead gaskets in gas meter couplings can be melted if care is not taken. Heat may be detected by placing the hand on the meter couplings. To play safe, the main house switch should be disconnected.

4. Make certain of the pipe material in use and make allowances in the current applied.

5. Make sure that wires from energy sources are adequate and that good electrical contacts are afforded. Scraping of the pipe surface may be required. Distance between connections should be as short as possible.

6. Open the pipe before thawing. This will let you know when water is beginning to flow. It avoids the possibility of steam pressure developing.

DEMONSTRATION BY J. DAWSON.

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**MAINTENANCE OF WATER METERS**

by

**C. Greer**

**Sales & Advertising Manager - Neptune Meter Company**

**An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961**

## MAINTENANCE OF WATER METERS

C. Greer

Sales & Advertising Manager - Neptune Meter Company

The necessity of properly maintaining consumer meters is obvious, and should be carried out by trained personnel in a meter shop well equipped to do such maintenance, the major equipment consisting of a test bench of sufficient size to handle a reasonable number of meters at one time in comparison with the numbers of meters in the system, suitable cleaning facilities and other accessory equipment to carry out the work with sufficient stocks of parts on hand.

The equity of sale of water to each consumer is dependent on this proper maintenance. Water meters of the type used by municipalities in this country begin to under-register as they become worn. Therefore, if meters are allowed to stay in service, in need of repair, their accuracy at low rates of flow deteriorates. Meters which are badly worn indicate only a percentage of the actual amount or when the flow drops low enough, do not indicate registration at all. The consumer fortunate enough to have an old meter on the service will be obtaining water at the expense of others.

The loss of water at low rates of flow begins to show a gradual increase in the per capita consumption as the water meters are allowing water to pass through hundreds and possibly thousands of units depending on the municipality, at the low or leak flows where plumbing fixtures begin to pass water if not kept in good repair.

It is necessary to keep consumer meters in good repair, to enable the water department to keep a running check on unaccounted-for water by comparison of total readings over a period of time against the reading of master meter or meters feeding the water into the distribution system.

Last and most important, it is essential to keep meters registering accurately, to provide the water department a fair return for their product to operate on a sound economical basis.

In drawing comparison between three types of utility services - water, electricity and gas, it is universal practice to meter gas and electric energy and is mandatory, at stated periods, by the regulations of the Standards Division of the Department of Trade & Commerce to check for accuracy and repair, if necessary, both gas and electric meters at stated intervals. Some years ago investigations were conducted by the Department of Trade & Commerce. After investigation it was decided nothing was to be gained and only additional costs would result to both Government and the utility if this was carried out insofar as water meters were concerned.



They found all meters manufactured and offered for sale on this continent and in general use domestically conform to the specifications of the American Water Works Association whose test requirements were adequate. Also, nearly all of our municipalities using water meters already had installed test equipment and were conducting accuracy checks at regular intervals. The water meters used in this country on domestic services of the oscillating piston or nutating disc type will not over-register beyond the allowable limits of plus 1 1/2% due to wear or any other cause which we understand is not the case of gas or electric measuring devices.

It is also practically impossible to leak electrically or gas, it just doesn't occur. If a short develops in an electric service, a fuse is blown or a fire is started. If the gas service develops a leak, it is shut off immediately and repaired. This is essential for safety reasons.

The same is not true with water. If a tap or toilet or other fixture becomes worn and starts to leak, the water meter is called on to record these low or leak flows, to protect the utility's investment and to bring to the attention of the consumer the faulty unit must be attended to. All water meters will operate and give reasonable accuracy at medium and high rates of flow, even if in poor mechanical condition, but it must be remembered a great percentage of the water used in a home is at the rate of flow of below 3 or 4 gallons per minute. In tests conducted in Hartford, Conn. it was found that homes equipped with tank toilets, 27 to 50% of the total amount of water used was at rates of flow of less than 1 gallon per minute. Therefore, it is vitally important that the accuracy of water meters be preserved below the flow of 1 gallon per minute. If leaks occur, the meter is going to be called on to provide reasonable accurate readings below the rate of flow of 1 gallon per minute, when it is remembered that a 1/16" orifice will pass at 70 pounds pressure 58 gallons per hour, 1392 gallons per day, or 41,760 gallons per month U.S. When leaks occur, they are, of course, at rates of flow below this, therefore it is essential to keep meters in good condition to act as Cash Register and Policeman of the water department.

It is surprising to discover that some water departments pay little attention to the water meter after it has been bought and installed. In some the water meters are actually allowed to remain in service until such time as they fail to register.

The quality of water varies greatly across Canada. In western Canada we have generally throughout the Prairies an alkali condition which promotes accelerated wear and deterioration. In some localities in the Maritimes are mineral springs and water with traces of sulphur which may defy entire elimination and give an acid condition and more rapid deterioration of valves, piping, fittings, meters, etc. Generally, however, in

Ontario surface supplies such as the Great Lakes chain and supplementary rivers have an excellent quality of water from a metering standpoint. This provides increased length of service from meters under normal service conditions.

In one water department drawing water from the Great Lakes system two lots of 25 each 5/8" meters which had been in average domestic service for 23 years without attention, were brought in for a special test to determine their condition and the time interval for a repair program. These meters were tested at normal test rate plus two additional rates from 1 gallon down to .21 gallons per minute. Forty of the meters tested were within the test requirements of new meters and the other ten were in various stages of needing attention, although all registered well at 1 gallon per minute. Further checking revealed the ten meters, in question, had been installed on services which were much heavier in demand than the average consumption. Unfortunately, figures on the consumption are not available and the above is only mentioned as proof of the blandness of the Great Lakes water supply. It is not suggested that meters should be left in service 23 years without attention, as there is no doubt, that these meters were all in a condition where the cost of repairing would be higher, as more parts would have to be replaced due to wear, to put these units back in a condition to stand up to the next term without failure or loss of accuracy before periodic inspection and test.

From the above it would therefore be evident that the maintenance and test period for 5/8" domestic size meters in particular should be determined by the individual utility, since the following factors apply as well as the before-mentioned.

First, the quality of water. It may be (a) bland, (b) alkali, (c) acidic, (d) extra hard, (e) carrying solids, sand etc. Secondly, the proper sizing of the meter to the service requirements.

Meters supplied to A.W.W.A. specifications, or generally, meters manufactured in North America are amply sized to easily take care of the full flow of the same size of service pipe. Referring to A.W.W.A. Meter Manual M6 on page 26 under "Safe Maximum Operating Capacity" is given the recommendations for safe operating capacity of all sizes of meters but for the point which is being discussed here, the 5/8" size rated at 20 U.S. gallons per minute or 16.5 Imperial gallons per minute maximum capacity, not test rates of flow. Naturally, if without obtaining reasonable definite knowledge as to the normal and maximum rates of flow obtaining in a service and a smaller size meter is used, it may be grievously overworked and require more frequent attention to keep it in proper sensitivity and efficiency. Where there is any question, a chart recording register can be utilized to determine the maximum and normal rates of flow. This unit is of considerable value on larger sizes of service, e.g. 3, 4, 6" and larger, which may be serviced adequately with meters by one or even two sizes smaller.

From the foregoing it should be evident that no definite period of repair and test covering meters across Canada under varying conditions in different municipalities could be arrived at. Conceivably a meter in Brockville could be in better condition both mechanically and sensitively after 15 years service than one in some portions of western Canada or even some municipalities in Southwestern Ontario. Obviously it is not possible to decide that because a certain municipality checks its meters every seven years that this should be the same for any other. Considering quality of water perhaps we could say that all water supplies from the Great Lakes system should be uniform. This would apply only if all rates, pressures and even prosperity of the users were the same. Each water works should endeavor to determine for themselves the period for their conditions. In many instances the greater percentage of 5/8" meters in many municipalities could be left as long as 15 years and others perhaps 5, 6 or 7 is indicated. Meters of the same 5/8" size, which have a heavy use on commercial services, should have a more frequent check.

In some water departments the repair and test period is based directly on the amount of water passed through since the meters' last overhaul. This may be costly to follow up with efficiency and that a regular period can better be determined in the individual municipality for 5/8" domestic meters. Information on the subject is given in Table 7.1, Chapter 7 of A.W.W.A. Meter Manual.

Municipalities who have meters in service for approximately 20 years without periodic repair, carried out only when stoppage results, should contact the meter manufacturer for a listing of serial numbers and the year manufactured from which can be picked groups of 5/8" meters of varying ages and average service. These meters can be given a thorough accuracy test as removed, care being taken to cork the inlet and outlet so that the meter will not dry out and test as soon as possible after removal from service. If such information is available, it will be of great help to know how much water has passed through each meter. Of course, the tested meters should be, if it can be determined, meters which have not been repaired since the original installation.

Following the above procedure and using rates of flow suggested by A. W. W. A., accurate data can be acquired as to the proper length of time for carrying out periodic inspection.

So far the larger sizes of meters have not been mentioned as the 5/8" or domestic meter size is in use in such relative large numbers and incidentally of much greater importance from a low flow loss standpoint. This has been stressed as the major problem. Small leaks are more apt to occur in the house services due to the numbers of outlets and also the large number of services. Leakage waste is more often found in the domestic service rather than in industry, although wasteful use in large quantities and at higher rates of flow do occur in industry. As previously mentioned, the displacement meter is very unlikely to slip in its

registration at the higher rates of flow. It first starts to deteriorate at low or leak rate which is an indication it is time it is rehabilitated.

It is the usual practice to remove 5/8" to 2" meters from the services for periodic inspection and test, replacing them with others on the services. Repairs and testing are carried out in the water works repair department and the meters made ready for re-installation.

Water meters larger than 2" are usually checked for accuracy on the installation as it is not economical in an average size of municipality to have spare units on hand. The cost of removing and re-installing has also to be considered along with the equipment which would be required to carry out such a project.

The larger sized meters are responsible for the recording of large volumes of water and therefore relatively high cost to the industry and great revenue to the water department, therefore should be checked, if not repaired, much more frequently. Many municipalities check all 3" and larger meters annually. Provision on each installation should be made to allow this to be carried out. All installations should be made with a by-pass and sealed valve so that the meter can be checked in service without interruption of the same to the customer, at any time.

If the meter has not a built-in test plug, a test tee should be installed at the meter outlet so that a 2 or 3" positive test meter can be used as the test unit. This meter should be checked often on the water department test bench. This is connected by hoses to the meter to be checked for accuracy or repair. The service being provided by the by-pass while tests or repairs are being conducted. The water passes to waste through the service meter and test meter. By comparing the readings, the service meter's condition can be determined. If the installation is properly made for such tests, the efficiency of a large meter can be obtained in a minimum of time with relatively inexpensive equipment. The majority of meters 3" size and up could well be checked annually in the above manner and for test results, the period of proper time to clean and repair and recalibrate become evident.

You will notice A. W. W. A. Meter Manual #M6 has been referred to previously, which should provide a good guide for those intending to carry out periodic inspection of meters. Chapter 7 of this article is quoted here.

Although it has taken a great many years to obtain general acceptance of the use of water meters as the most equitable basis for charging for water service, full benefits from metering are not obtained unless a definite program of meter maintenance is carried out.



## Purpose of Testing.

A water meter, like any other mechanical device, is subject to wear and, over a period of time, loses its peak efficiency. How long water meters retain their overall accuracy depends largely on the quality of water being measured. There are several other factors, however, that cause excessive wear or inaccurate registration. Obviously, although the only way to determine whether any specific meter is operating efficiently is to test it, the problem of establishing a meter maintenance program is how to determine the frequency for testing every meter in service. From an individual customer's viewpoint, meters should be tested to protect him against meter inaccuracy that could result in overcharges. This, of course, is also of concern to utility management. Experience shows, however, that the greater concern of a water utility should be the revenue loss that results from the under-registration of meters.

The economic advantage of meter maintenance programs has been recorded in many articles, but most of them have invariably covered concentrated efforts to rehabilitate meters after a long period of non-maintenance and are of little value in answering the question of how often meters should be tested under a program of meter testing on a sustained, continuous basis. Unfortunately there can be no single answer, as the economic result depends on such factors as the rates charged for water, the effect of waters of different quality on meters, and the cost of removal, testing, repairing, and installation of meters. A reasonably proper economic balance should be attained. If meters are not adequately maintained, loss of revenue to the utility results. Conversely, if the cost of a program of meter maintenance is more than the loss of revenue that would occur if the meters were not tested, the overall result is economic waste and the utility's customers are required to pay for unnecessary expense.

## Test Frequency

Although many state regulatory commissions have adopted regulations concerning frequency of meter tests, it should be noted that any arbitrary time interval applied to several localities, each with its own conditions, cannot be economically correct for all. Table 7.1, compiled in 1954, is a listing of these regulations. It must be recognized, however, that the very existence of such regulations has often caused meters to be better maintained than without such regulations. It is inexplicable, but true, that meter maintenance in too many instances is considered of little importance, as something which is done only when other types of work cannot be readily deferred are out of the way. Only when meters are truly recognized as the means by which revenue is obtained to operate the water system will the necessary time and study be given to the question of how frequently it is necessary

to test meters for most efficient and economic results.

What are some of the things that must be known in order to establish time or registration intervals between tests? One, of course, with a fully metered system, it is the percentage of water delivered to the distribution system which is registered by customers' meters. This is known as the "metered ratio". The expression "Percentage accounted for" is not used here, as there are so many methods and bases for estimates of unmetered uses that comparisons of water accounted for are often meaningless. If a low percentage of the total water delivered to the distribution system in a year, such as 60 - 70%, is recorded by all customers' meters, this is indicative of inefficiency, and may be the result of under-registration of meters, undue leakage in mains and services, or the combination of both. Even when a water system is only partially metered, a marked variation in the percentage from year to year should be investigated.

Practically no study that is made, however, can tell how much loss is due to the under-registration of meters. This amount can only be determined by testing. Some indication can be obtained by installing new meters in series with old meters in service and, by selective sampling, projecting the probable loss due to under-registration for meters that have been in service for a certain period of years. If meters of different makes and various models are used, such sampling can become quite complex and the results may be of dubious value. There is, however, a very distinct value in such in-service comparisons - that is, to show conclusively how much under-registration and resultant loss in revenue occurs if meters are not maintained in good operating condition.

#### Program Co-ordination

To start a program of periodic testing, it is necessary to adopt an arbitrary period in which to complete the work, and it is desirable to select a period of years that coincides with the best estimate of frequency, with which meters should be tested. In this way the work is leveled out, and the next time meters are tested nearly the same number of meters are due for test each year. If, for example, a utility with 10,000 meters in service sets up a program for testing meters on a 10 year cycle, it has to remove approximately 900 meters each year. This is less than 10% of the number in service, as there are always meters that will not remain in service for the full period and will be removed for other reasons. In order to provide for even work flow, both in the changing of meters and shop work, it is preferable to have the number of orders required, prepared on a daily basis. Assuming 250 working days in a year in order to complete the periodic testing of 900 meters per year, the testing of roughly 4 meters each day would be necessary in addition to the other required work. If, therefore, four orders are written each day, progress

of the program may be reviewed at any time by a count of the number of uncompleted orders for changing meters for periodic test and a check to see if the shop work is getting done without building up a backlog of meters. Although the testing of 10,000 meters may seem a staggering job, it is surprising, once the work is started on a systematic basis, how the additional work is absorbed as soon as it becomes routine. Obviously, as actual test results of meters removed from service are accumulated, experience is obtained as to the length of time it takes, on the average, for meters to lose sensitivity on low flows and the length of time meters are permitted to remain in service can be adjusted on the basis of known results.

It is generally considered advisable to provide for more frequent tests of large meters, on the logical premise that an error in their registration affects revenue to a much greater extent. Furthermore, current and compound meters may over-register to a much greater degree than positive displacement meters. If a sufficient number of 3" or larger meters are installed, the repair and testing of these larger meters may be delegated to one particular person or crew and divorced from the normal procedures set up for handling maintenance of small meters.

Probably the best advice which can be given on this involved and difficult problem is to be alert to, and study all phases of, the subject, as there is no substitute for experience in arriving at the best answer. It should be constantly borne in mind, however, that, although a metered system is the best basis known for equitably spreading the cost of the water service, serious inequities and injustice can be introduced unless all meters are maintained at a high, uniform level of efficiency and unless every reasonable effort is made to see that these inequities do not occur.



PIPING AND CONNECTIONS

by

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An Address To  
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## PIPING AND CONNECTIONS

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### INTRODUCTION

Many construction materials have been used to carry water. First, with gravity flow, and later, with flow under pressure. Stone, vitrified clay, wood, lead, copper, cast iron, wrought iron, steel, cement, concrete, even bamboo, and various combinations of materials, have all been used. It is worthwhile to have some knowledge of the older pipe materials, because some of these presently little used materials are still in service in many of the older water systems. Modern types of pipe commonly used for carrying water under pressure include cast iron, asbestos cement, steel, and plain and prestressed reinforced concrete, with or without an internal steel cylinder. In the smaller sizes of distribution piping, steel, wrought iron, cast iron, copper, brass, lead, and even synthetic materials, are in common use. Plastic pipe, a relative newcomer in the field, is being actively developed, tested, and installed in sizes ranging up to twelve inches in diameter. There still remains in service, particularly in the North-eastern United States, many pipe lines of cement-lined and coated sheet iron, installed during the middle of the Nineteenth Century. In many sections of the country, wood stave and rivetted or lockbar steel pipe lines, laid early in this century, are continuing to serve as water carriers.

#### Cast Iron Pipe

The first recorded use of cast iron pipe was in Germany in 1455. In the fountains at Versailles, France, cast iron mains laid in 1644 are still in service. The earliest recorded use of cast iron pipe in water distribution systems in the United States was in Philadelphia in 1817. The material is highly resistant to corrosion, and has other desirable properties. With the exception of pipe laid in corrosive locations, few cast iron pipe lines have deteriorated sufficiently in physical condition to establish a measure of their ultimate life. There have been four chief types of cast iron pipe, differentiated by the method of manufacture. Firstly, horizontally cast; secondly, pit cast, a vertical cast in sand moulds; thirdly, centrifugally cast in sand-lined moulds; fourthly, centrifugally cast in metal moulds. Only the last two types of cast iron pipe are in general production today.

Cast iron pipe was originally used without special coating or lining. Later, the cast pipe was dipped into a vat to coat and line it with a coal tar pitch varnish or enamel. Such linings do not protect the interior surface for long from action of certain waters, and subsequent pitting and the formation of growths known as tubercles, substantially increase friction and reduce carrying capacity. A method of lining with cement mortar was introduced about 1920. This lining, together with thicker centrifugally applied bituminous lining, protects the interior of the pipe from tuberculation, and preserves its carrying capacity. Except in certain locations, or under special conditions, most cast iron pipe now being installed is lined with cement mortar or bituminous enamel. Friction losses in older unlined pipe may be, and frequently are, more than twice as much as in lined pipe.

### Asbestos Cement Pipe

Asbestos cement pipe, in use for over thirty years, is composed of asbestos fibre and Portland Cement mortar, combined under pressure with a homogeneous structure in which a strong bond is effected between the two materials. Among its advantages are a high resistance to corrosive conditions, freedom from electrolysis, its ease of handling, installation, jointing and tapping, flexible joints, and a high sustained carrying capacity under most conditions. Some disadvantages are its relatively low resistance to flexural stresses, causing breakage and necessitating care in bedding and installation, its susceptibility to puncture by rocks or tools, and its nonconductivity, which makes electric thawing impossible.

### Steel Pipe

Steel pipe has long been used for water distribution. The development of welding techniques has increased the use of steel pipe, particularly in larger sizes. It is lighter in weight than cast iron or concrete, and is easily cut and welded. It is easily installed and jointed, has some flexibility in action, and can be designed in thickness and strength to meet the most severe conditions. It is, however, less durable and sometimes more expensive than competitive pipe. Although protective linings and coatings can be applied to increase its durability and service life, such linings are, however, sometimes adversely affected by the flexibility of the pipe if subjected to bending from trench loads.

### Reinforced Concrete Pipe

Reinforced concrete pipe has long been used for the larger sizes of transmission and distribution mains. Since the advent of prestressed concrete pipe in the early 1940's, more and more of

this type of pipe has been used in sixteen inch sizes and larger. It is generally more economical in these sizes than other types of pipe. It has the advantages of durability, strength, flexible joints, sustained carrying capacity, and ease of installation. Although it is heavy and somewhat difficult and costly to tap, its many advantageous features have rapidly brought modern prestressed concrete pipe to the fore among the types of pipe used in larger sizes for distribution systems.

### Plastic Pipe

The introduction of plastics as pipe material in the past few years has raised increasing interest in this material for water system use. In small sizes, it is being used more and more. For instance, in service lines. It is light in weight, generally non-corrosive, and has a high carrying capacity. The jointing problem is being satisfactorily solved. The installation of plastic may, in time, take the form of a more or less continuous extrusion process. Undoubtedly, plastic pipe will become more and more used as refinements in materials, manufacture, and installation, progress.

### FITTINGS

The basic material for special fittings required in the pipe system, such as tees, crosses, and bends, are cast iron and steel. The use of cast iron fittings with cast iron and asbestos cement pipe is considered standard. These fittings can also be used with concrete and steel pipe with suitable adapters. Asbestos cement pipe also requires adapters for eight inch and larger sizes. Madeup concrete and steel fittings are also provided by the manufacturer of those types of pipes.

### JOINTING MATERIALS AND METHODS

Until about 1935, the common type of joint for cast iron pipe was the bell and spigot joint. After assembling the pipe by inserting the spigot into the bell end, the joint was made tight by packing strands of jute or yarn in the joint, and then pouring a molten material, caulking it after hardening to seal the joint. At first, lead was commonly used for this purpose. About 1920, various sulphur compound materials were substituted for the lead and came into common use. In some parts of the country, cement joints made of neat cements slightly moistened and caulked, were quite commonly used. The next development was a bolted type of mechanical joint, consisting of a follower ring pulled up by a blot to compress a rubber gasket. This joint largely displaced the poured joint. It provided water tightness under pressure, as well as joint flexibility. Since 1955, rubber gasketed bell and spigot

slip joints have largely superseded all other types of joints for use with cast iron pipe. These are provided by various manufacturers under trade names. All essentially consist of a rubber or composition gasket, fitted and held in the bell end of the joint, the spigot end being shoved into the bell, compressing the gasket. Water tightness, flexibility, and ease and economy of installation, are all features of this type of joint. Asbestos cement pipe is joined with a roll-on rubber gasket coupling made of similar material. Steel pipe may be welded or have plain ends joined with mechanical rubber gasket coupling. Concrete pipe uses slip-on rubber gasketed bell and spigot joints, similar to those now used with cast iron pipe.

## VALVES AND HYDRANTS

The selection and location of valves and hydrants is of great importance to a properly designed distribution system. As valves form a part of the pipe system and remain in service for many years, care should be exercised in selecting them for steady and long-lasting service.

### Valves

The standard valve for distribution service has, in the past, been the double disc, parallel seat, cast iron valve, with bronze mounted seat and gate rings, wedges, and non-rising stem. Normally, valves are placed in the pipe line with a valve box extending to the street surface. They have a nut at the top, over which is fitted a gate key for opening and closing the valve. Frequently, larger valves are placed in vaults with manhole accesses to vacillitate operation and maintenance. Large valves generally are equipped with small bypass valves to reduce pressure differentials on opening and closing, and often have spur or bevel gearing to reduce the labour of operation. If valves are laid horizontally in the pipe line, care should be taken to have the valves equipped with bronze or Babbitt tracks to carry the weight of the gates throughout their travel on rollers or shoes. Double disc valves, with inclined seats, and solid wedge type valves, are also used in distribution pipe lines. Recently, and more commonly in the larger sizes, rubber seated butterfly valves are being increasingly used in distribution installations.

### Hydrants

Fire hydrants for ordinary water service are usually one of two types of post hydrant; the compression type, opening against or with pressure, and the gate type. They may have from one to four nozzles, the most common being equipped with two 2½" hose nozzles



and one 4" steamer or pumper nozzle. The size of hydrant refers to the size of the hydrant main valve opening, which may vary from four to six inches in diameter. For two hose nozzles and one steamer nozzle, a hydrant usually should have at least a 5" valve opening. The length of a hydrant, or bury, is the distance from the bottom of the connecting pipe to the ground line at the hydrant, and is generally given in units of half foot. Hydrant barrels are of cast iron, with moving parts such as valve facings, being of bronze or other non-corrodible materials. The barrel and operating mechanism should be so designed that, in the event of damage or breaking of the hydrant above or near the grade level, the main valve will remain reasonably tight against leaking or flooding.

## DESIGN REQUIREMENTS

Pipe and special fittings used in distribution systems must be designed to withstand the various forces acting upon them. They must withstand internal water pressure induced by static and kinetic pressures, and such shock pressures as result from water hammer. They must withstand external pressures acting upon them, such as from trench loads, and live loads resulting from heavy traffic and impact. Pipe is generally purchased for several standard ratings. In common practice, pipe is designed for four classes of working pressures: 100 pounds per square inch, 150 pounds per square inch, 200 pounds per square inch, and 250 pounds per square inch. Pipe is tested to several times the normal working pressures, and allowances are made for water hammer. Exterior trench and traffic loadings must similarly be provided for, as to the shape, width, and depth of the trench, as well as methods of backfilling. All these factors play a part in how much exterior pressures are exerted on the pipe. Design tables for determining the thickness of metal required in various sizes of pit cast and centrifugally cast pipe under varying internal pressures, trench conditions, and depth of cover, have been promulgated as part of the A.W.W.A. specification, C-101. The specification for asbestos cement water pipe is a tentative specification, A.W.W.A., C-400-53T.

## SELECTION OF MATERIAL

A number of factors must be weighed in selecting the best type of pipe for installation in any system, or even in different parts of the system. Relative cost, availability, durability, the initial and sustained carrying capacity, and ease and economy of installation and maintenance should all be considered. Of the pipe materials presently being used, cast iron and prestressed concrete are the most rugged and durable. In streets with heavy traffic and good pavement, the most durable materials should be used to ensure long life and low maintenance costs. On less important streets and private right-of-way, durability is not so important if economies

can otherwise be effected. All pipe line installations should be designed for the maximum pressure they are likely to undergo, as well as for the particular trench loadings expected. Special installations, such as sub-aqueous, a stream crossing, installation on bridges, or important highway or railway crossings, may require special treatment. In addition to the cost of material, the expense of installation is important. Pipe manufacturers, by continuous research over the years, have developed new methods of joining pipe to save labour costs. The progress made in methods of joining pipe has produced joints that are about as economical and easy to make as appears possible. Contractors are sometimes slow to accept new methods of installation and to pass along the resulting reduction in cost. In time, competition forces them to do so. In simplifying their products, pipe manufacturers have reduced the length of shutdown time and labour needed to make repairs. A certain amount of repair and maintenance work is unavoidable, and a stock of repair items must be maintained. Overstocking of repair items should be avoided, but a sufficient supply of items should always be kept on hand for routine repairs. Not only are stock repair items important, but an experienced supervisor on the job can contribute immeasurably to the efficiency of the work, and reduce the length of service interruptions.

## INSTALLATION

The installation of water mains involved transporting and handling the pipe and appurtenances, ditching and excavation, laying, joining, testing, and disinfecting the pipe, backfilling the trench, and replacement of road paving and sidewalk surfaces. Complete specifications for the installation of pipe and fittings are given in an A.W.W.A. Standard, C-600. When pipes, special valves, and other appurtenances to a waterworks distribution system are delivered to the site of the work, they should be inspected for defects, and all rejected parts should be immediately removed from the work. If they are left lying around the job, sooner or later they will become part of it. In our utility, it has been the practice, in the past, to have an independent testing company examine the pipe prior to delivery, and this is an excellent way of weeding out the defects prior to shipment, but they should also be inspected after delivery to check for shipping damage.

## EXCAVATION

Excavation can be carried out in several approved ways: by hand, labour, power shovel, backhoe, or trenching machine. In many respects, the backhoe has proved to be a good piece of equipment for installing pipe, particularly in the larger sizes. It is effective in doing the excavation, and can handle the pipe from the trench side to its completed installation. We use extensively a



hydraulic operated backhoe and front end loader, and we have found this to be very satisfactory for not only doing pipe installation, but also service installations. The trench should be opened only so far in advance of pipe installation as is necessary. It is best to keep the trench as narrow as possible and to shape the bottom of the trench to form a complete bed. Blocking should be preferably not used under pipe, but if it is used, it should be removed as soon as preliminary tamping of fill around the pipe provides full bearing. If rock is encountered, or if the bottom material is undesirable for bedding, it should be excavated at least six inches below the grade and refilled with sand or fine gravel tamped in place.

### Laying and Jointing

When the trench is suitably prepared, the pipe must be lowered and joined. Care must be exercised in handling so that it is not damaged. Various pipe manufacturers give special instructions for the handling and jointing of their pipe. Because the shove-in or roll-on pipe joints have largely replaced joints poured with lead, sulphur compounds, and cement, details of these older joints are not discussed here. Sulphur compound joints were commonly used for cast iron pipe during the period 1920 to 1950. Much trouble has been and is being experienced with joint failures and breakage of the bells of such joints under certain soil conditions. This is generally attributed to the expansion of the joint material and much controversy has arisen concerning it. Not much can be done to correct such installations, except at considerable expense. Bell clamps may be used successfully in stopping breakage, or the joints can be cut out and refilled with some other joint material. The joining of the pipe should be done carefully. Each type of pipe requires special joining procedures. The distinctive sound of a joint being home should be heard on pushing the pipe together. If rubber gaskets are used, an inspection of the completed joint should be made with feelers or some other method, to ensure that the gaskets are properly seated. The newer types of joint are usually pulled together with come-alongs, bars, a backhoe, or a bucket and sling. The same methods are used in installing valves, fittings, and fire hydrants, as with straight pipe.

### Valves, Hydrants and Fittings

Valves should be placed in some standard area, such as at street or curb lines, to facilitate their location. A valve box should always be placed over a buried valve with its cover at the street grade. Gear valves sometimes have enclosed gear and grease cases and are placed directly in the ground. Large valves are often placed in brick or concrete vaults. Fire hydrants should

be so located as to be completely accessible to the Fire Department and yet, as far as possible, be protected from damage from vehicles and out of the path of pedestrians. Hydrant nozzles should be set to grade and not less than twelve inches above grade. They should be so pointed as to be accessible, but should be a sufficient distance back from curb lines to escape vehicle damage. Fire hydrants are now rarely connected to distribution mains, except through properly gated six inch or larger hydrant laterals. Hydrants are made to be self-drained through drain ports which shut off. To accomplish this drainage, a pocket filled with gravel or crushed stone, at least two feet in diameter, should be provided under and around the hydrant base. In clay ground, this pocket may need to be larger. The hydrant and lateral should both be braced or tied with rods to protect against shifting due to unbalanced water pressure. Blocking or firmly positioning tees, bends, caps, plugs, hydrants, and other fittings, is an important part of pipe line installation. Any unbalanced pressure in a pipe line must be counterbalanced with blocking or positive ties, inasmuch as modern joints can easily be pulled apart. Sleeves are often used in the assembly of valves and pipe lines. Care should be taken that pipe is solidly together or spaces should be provided to prevent lengthwise movement of the pipe resulting from the unbalanced pressure exerted by valve closure.

#### Backfill and Surface Restoration

After pipe, fittings, valves, and other appurtenances, are installed and inspected, a selected backfill is placed in the trench. That is, the backfill should be free from rocks, large stones, cinders, or other unsuitable substances, to avoid damage and to produce a dense, compact backfill. Backfill material should be tamped in layers around the pipe, and for a height of at least twelve inches over the pipe barrel. If possible, joints should be exposed until pressure and leakage tests are concluded. Where trench settlement is unimportant, the remainder of the trench can be filled with excavated material, pushed in by bulldozers and mounded over the pipe trench. In streets or other locations, where settlement is undesirable, the backfill should be consolidated by tamping or by flooding with water to the top of the trench. Local highway regulations often dictate what the backfill shall consist of, and what methods should be used to replace it. Proper restoration of paving, sidewalks, lawns, or shrubbery, is important for the general public will remember the restoration and cleanup much longer than the reason for installing the invisible main.

#### Leakage Test

All new main installations should be tested for pressure

and leakage, and also should be disinfected and flushed. The procedure for doing this can be obtained from various places. The leak and pressure test is outlined in the A.W.W.A. Specification C-600.

### Disinfection of Mains

Although precautions may have been taken during installation to keep the interior of pipe and appurtenances free from debris and contamination, flushing and disinfection of the main is carried out to ensure that a safe potable water is delivered to customers. The best precaution is to swab out the pipe before installation. The use of bulkheads at the termination of the day's work prevents animals, insects, and surface drainage from entering the pipe during the night hours. In spite of precautions, foreign substances will usually get into the pipe, so flushing and sterilization are required. A good flushing of the line under pressure should be carried out to remove any dirt and debris which may have entered the line. This pipe should be of sufficient size and in such a location as to permit the debris and dirt in the pipe to be completely removed. It is also essential that the flushing remove the heavily chlorinated water before the main is placed in service.

### Emergency Repairs

Damages to a pipe system due to emergencies and disasters are unpredictable. Water system operators should be prepared to put a plan of repair into operation whenever needed. Every utility should have an effective plan to cover emergencies such as floods, landslides, fires, explosions, severe cold spells, and the usual problems, such as split pipes, blown joints, and broken valves and hydrants. Equipment should always be available and ready for emergency repairs. Excavating equipment, pavement breakers, pipe cutters, ditch pumps, chlorinating equipment, floodlights, generators, and welding equipment, should be available in permanent stock or on an emergency basis through agreement with outside sources. Many types of materials will be needed, such as spare pipe and fittings, repair clamps, bell joint clamps, and particularly sleeves and mechanical couplings. Spare parts for valves and hydrants, as well as a reasonable number of complete spare units, should be available. Work crews should be trained to be alert and know how to tackle the various normal emergencies, which all systems experience at times. The rapidity in which repairs can be accomplished may be an important element in reducing damages and damage claims. All the precautions taken for new work, such as disinfection, flushing, and hydrostatic testing, should also be taken when making major repairs. Much of the equipment which we have just mentioned will be demonstrated to you later on this afternoon.

## Service Connections

The pipe leading from the distribution main to the plumbing system of individual premises is commonly called a service line. Each service line consists of two main parts; the service connection, which extends from the main in the street to the curb or property line, and is usually, though not always, installed by the utility, and secondly, the portion which extends from the curb or property line to the building, and is usually installed at the customer's expense.

## Service Connection Components

Each service connection consists essentially of a connection to the distribution main, a length of service pipe leading to a curb cock or turnoff valve located at the property line, and another length of service pipe to the plumbing system of the premises. A service pipe is generally connected to the distribution main by means of a corporation stop inserted in the main. The insertion is normally accomplished while the main is in service and under pressure, and is thus known as a wet connection. Occasionally, outlets are provided in the main when it is originally installed, particularly if the service connections are large. The corporation stop can be turned to shut off the flow in the service line, as is often done to reduce the possibility of leakage when the service connection is discontinued. Ordinarily, water service to the premises is turned on or off at the curb stop located near the curb and accessible through a curb box placed over it.

Every water utility should have definite regulations and specifications for service and meter installation, and should set forth responsibility for payment of costs. The specifications may be in the form of sketches, which detail how the service line is to be installed, sizes and kinds of approved service line materials, and any other information necessary to provide a complete understanding of installation requirements. Lack of such knowledge on the part of the customer often can result in misunderstandings and strained relations.

## Selection of Materials

The cost of installing customer service connections, that portion of the service from the main to the curb or property line, commonly exceeds ten per cent of the total investment of a water utility. It is important, therefore, that every effort be made to select service line materials that will give the longest possible satisfactory service. The most important factor affecting the useful life of service lines is the ability of materials used to resist internal and external corrosion. Internal corrosion may be of two general forms; pitting, which results in failure of the pipe or



fitting material to withstand pressure and causes blowouts or leakage, and tuberculation, which reduces the carrying capacity of the pipe. These actions may progress so far that the service line must be replaced. Obviously, the material selected for service lines must have sufficient strength to withstand the maximum pressures to which they may be subjected. The type of material used for service installations should be chosen only after consideration has been given to all pertinent factors. True cost involves life expectancy, as well as the original cost. Leaking service lines are one of the most expensive maintenance problems in water utility operations, and replacement costs are high. In addition, faulty services are a primary source of unaccounted for water. Materials most commonly used for service lines include copper, brass, lead, cast iron, black and galvanized wrought iron and steel, asbestos cement, and plastics of various types. Lead was one of the earliest materials commonly used for service piping. It was flexible, with relatively long life and sustained carrying capacity. Because of the high cost, both the material itself and the labour in jointing is not commonly used today. Brass is another material that was once used, although not so extensively. Both red and yellow brass pipe have fairly long lives and sustained carrying capacity, but they are subject to rapid corrosion under some conditions. This is particularly true of yellow brass. Brass pipe is rigid, requires threaded couplings, and is costly. Black and galvanized steel pipe and wrought iron pipe, both unlined and cement lined, have been used successfully for many years. They are rigid, require threading, and therefore, are not easy to instal. They have relatively short lives, owing to their susceptibility to the corrosive action of soil and the water inside the pipe, as well as to galvanic corrosion, resulting from contact with bronze corporation and curb stops. Cast iron and asbestos cement pipe are used for larger service, generally in two-inch size or larger. Both have excellent corrosion resistance and retain carrying capacity well.

Many types of plastic pipe, varying from soft, flexible ones, to hard, brittle ones, are becoming more and more available for service line installations. Some types are easy to instal with standard fittings and valves. Others require special fittings and jointing materials. The availability of various types of plastic pipe to withstand interior pressures as well as outside damage varies considerably. Most plastics are affected by temperature changes. Some plastics impart taste and odour to the water. Some are even toxic to humans, and should never be used in potable water systems. Fabrication of plastic pipe was begun about 1940, and has grown tremendously since 1950. In the beginning, it was used only for experimental water service installations, but its use is rapidly becoming more and more common because of its potentially low cost. The development of copper service pipe with practical types of connections has resulted in its wide and satisfactory use. Copper pipe is generally looked upon as a standard for comparison. It is popular for service line installations because it is flexible, easy

to instal, and corrosion resistant in most soils, and has a high sustained carrying capacity. It is not sufficiently soluble in water to be a health hazard. Brass and bronze fittings can be used with copper without causing appreciable galvanic action. The ends of ductile copper tubing can readily be flared to provide an easy method of attachment to fittings. It can withstand high pressures and can be frozen without failure. The ground conditions that are not favourable to the use of copper tubing are relatively few, but they are important to recognize. Copper does not stand up well where the soil is permeated with acid mine drainage water. Similarly, cast iron pipe is adversely affected in salt water marsh areas. In these, and other limited areas, asbestos cement pipe, or various kinds of plastic pipe, may be preferable.

### Service Installations

The method of making service connections at the main varies with the size and material of the service, and the size and material of the main to which it is attached. If the size and wall thickness of the main are sufficient to provide adequate full threads, three-quarter inch to two inch services may be connected by drilling and tapping of the main. Tapping machines designed for drilling, tapping, and insertion of the corporation stop under pressure are available. Tees, Y's, or special branch connections may be utilized for connecting larger service lines. In multiple tapping, corporation stops should be spaced at least ten inches apart and staggered around the pipe's circumference to avoid weakening the main pipe. If the wall of the main is too thin for direct tapping, or if the required number of full threads cannot be obtained, service clamps are necessary. In such cases, drilling is done through a corporation stop, which has already been screwed into the service clamp. Larger drilling machines are used to drill through tapping sleeves and valves for making lateral or branch connections to mains under pressure. If the main is out of service, and the service connection is large, it may be desirable to cut the pipe and insert a tee. The depth at which service lines are laid is of great importance. Additional depth, beyond that necessary to avoid freezing and to protect against traffic damage, imposes higher installation costs. On the other hand, maintenance costs during severe cold weather can be extremely high. The rate and extent of frost penetration is a function of the character of the soil, snow cover and the duration and intensity of air temperatures below freezing. Frost penetrates gravel more quickly than clay. Pavements are generally poor insulators, whereas snow cover is a good insulator. Service lines freeze more often than mains because there is a smaller volume of water to be cooled and longer periods of no water movement. One problem, when expensive pavement is to be installed, is to decide whether services should be installed to vacant lots in advance. Generally, the cost of such advance service connections is paid by the owner of the property. Of course, if the prospective use of such services is far in the future, or if

changes in lot size may make the use of such advance installations impossible, it would be uneconomical to instal them. Since the greater portion of the cost of installing service connections is labour, it is important that the service be of sufficient size to take care of the present and foreseeable needs and to keep the friction losses to a minimum. The size of service required for various installations is readily available from tables in various publications.

### Records

It is of vital importance to maintain a complete record of all services installed, in order that they may be located at any future date. There are several methods of maintaining service records. One may employ a service application book, in which the applications are numbered and the location of the premises and the applicant's name are given. Usually, however, an index card file is maintained, and pertinent information concerning each service installation is posted as it is received. Such information would include the permanent service number, the applicant's name and address, the date of application and installation of service, sizes of corporation and curb stops used, size and kind of pipe used, depth at which the service is laid, and detailed measurements of the service location. This file may be supported by a large scale map, on which the services are plotted in such detail as is found desirable.



# CHLORINATION

by

G. R. Trewin

Supervisor - Field Activities - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
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## CHLORINATION

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### PURPOSE OF CHLORINATION

Before planning an effective chlorination programme the full treatment objectives must be known. In general the objectives may be divided into three sections; taste and odour control, disinfection, and protection of the distribution system.

#### Disinfection

Disinfection is probably the first and most important function of chlorination. The destruction of pathogenic and taste and odour causing micro-organisms is of prime importance.

#### Taste and Odour Control

Tastes and odours created by biological growths, and or industrial waste can at times be controlled or eliminated by correct chlorination practices. Chlorophenolic tastes, which develop when small dosages of free chlorine contact phenolic like compounds, can be eliminated by practising superchlorination or using chlorine dioxide. The tastes can also be prevented in the first place by effecting disinfection with a combined residual. Other tastes may be controlled to varying degrees using the appropriate chlorination process.

#### Distribution System Control

Some Authorities feel that a chlorine residual should be maintained in a distribution system. The chlorine residual will keep the system free from taste and odour causing organisms. The residual will also tend to protect the distribution system from contamination caused by inadequately disinfected new or repaired sections of main, or the occurrence of back-siphonage from a non potable source. Nevertheless, maintaining a chlorine residual in the system is not a solution to poor construction or repair practise and it certainly does not condone poor plumbing

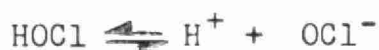
## CHLORINE CHEMISTRY

### Chemical Reactions of Chlorine in Water

Chlorine reacts with water to form hypochlorous acid and hydrochloric acid according to the equation:



In turn, the chlorine, as hypochlorous acid, dissociates into hydrogen ions and hypochlorite ions according to the equation:



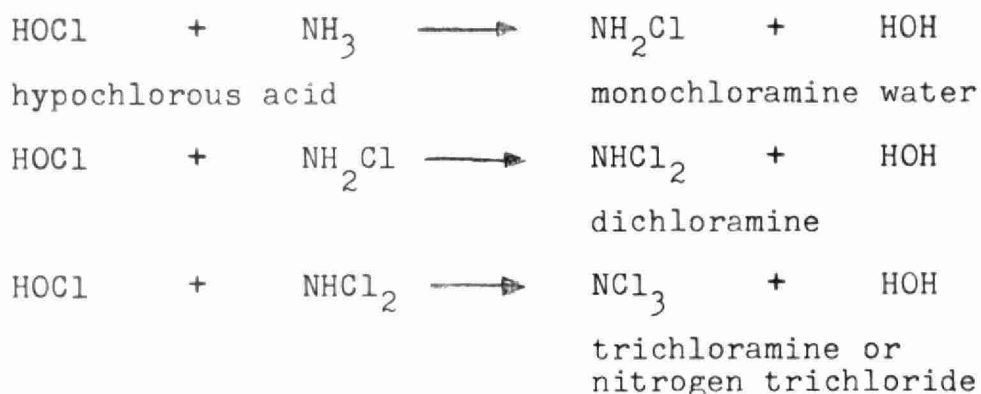
At a pH value of 5.0 or below, chlorine is present as  $\text{Cl}_2$ . When the pH value is between 5.0 and 6.0, the chlorine exists almost entirely as hypochlorous acid. Above pH 6.0 hypochlorite ions are present, becoming predominant above pH 7.5. The pH value of chlorinated water supplies is normally within the range where the chlorine exists as hypochlorous acid and hypochlorite ions.

Chlorine existing in water as hypochlorous acid and hypochlorite ions is defined as free available chlorine.

Chlorine is one of the most active chemical elements and its addition to water as a free available chlorine produces a variety of chemical reactions.

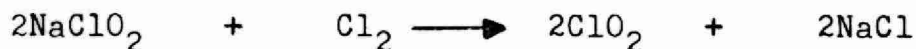
Free available chlorine reacts with ammonia to form chloramines, and with organic compounds containing nitrogen (such as proteins and amino acids) to form chloro derivatives. The Chloramines and chloro derivatives have a lower oxidation potential than that of free available chlorine, but the chlorine combined in these forms is still available for chemical reactions.

The following three equations represent three step wise reactions to form the chloramines:



Chlorine existing in water in chemical combination with ammonia or organic nitrogen compounds is defined as combined available chlorine.

Another chlorine compound used for disinfection purposes is chlorine dioxide. The reactions taking place to form this compound are many but for simplicity the following equation is submitted:



### Chlorine Demand

Chlorine demand is defined as the difference between the amount of chlorine added to water and the amount remaining at the end of a specified contact period. The demand will vary with the amount of chlorine applied, the time of contact and the temperature.

### Bacterial Action of Chlorine

The primary purpose of the addition of chlorine to water is to destroy bacteria and other micro organisms. Trace amounts of free available chlorine prove to be very effective in this intended purpose. One belief is that the destructive action is a physicochemical one. Another theory postulates that because trace amounts of chlorine are effective implies that it must inhibit a key-enzymatic process.

Any change in the state of the chlorine which reduces its oxidation potential as for example, its reaction with ammonia or ammonia derivatives to form combined chlorine residual - reduces the rate at which it reacts with the bacterial cells and decreases its effectiveness as a disinfecting agent.

### COMBINED RESIDUAL CHLORINATION

#### General

Combined residual chlorination is defined as the application of chlorine to water to produce, with the natural or added ammonia, a combined available chlorine residual. A combined available chlorine residual should contain little or no free available chlorine. A desirable combined residual is obtained with ammonia to chlorine ratios of 1:3 to 1:4. As the chlorine dosage is increased the ammonia will be oxidized. The break point, or complete destruction will occur when the chlorine dosage is between 10 and 25 times that of the ammonia, either natural or added, concentration.

Available data show that, under most favourable conditions: (a) to obtain equivalent bactericidal action with the same period of exposure, about 25 times as much combined available residual chlorine as free available chlorine residual is required and (b) to obtain equivalent bactericidal action with the same amount of combined available chlorine residual as free available residual, a contact period of approximately 100 times as long is required.

Besides the type of residual having an effect on the chlorine residual required to effect disinfection other factors such as pH, temperature, and type of water will also vary the requirements. See Fig. 1 for a residual requirement curve secured in the U.S. Public Health Service experiments at temperatures of from 20° to 25°C for 60 minutes exposure to combined available residual chlorine and 10 minutes exposure to free available residual chlorine.

The residuals suggested in the chart do not apply for turbid water.

#### Application of Combined Residual Chlorination

##### Disinfection

As indicated above much greater combined chlorine than free chlorine residual are required to effect disinfection unless of course a much longer contact period is allowed.

Generally marginal chlorination will produce a combined residual. Only very pure water containing little ammonia or protein type material will produce a free residual at low application rates.

##### Taste and Odour Control

Chlorine-ammonia treatment first came into general use to limit tastes and odours resulting from the chlorination of water containing phenolic substances; subsequently it has been found effective at times for reducing tastes and odours due to other substances. Combined residual chlorination produced by the chlorine-ammonia treatment, cannot, however, be considered a corrective for all taste and odour problems, since it frequently does not accomplish satisfactory results.

There are three chloramines formed with ammonia; mono-di- & trichloramine. The Trichloramine or nitrogen trichloride ( $\text{NCl}_3$ ) produces a very pungent odour and therefore, its prevention must be considered at all times. Only long aeration will remove nitrogen trichloride. The  $\text{NCl}_3$  is produced under low pH conditions and when the chlorine to ammonia ratio exceeds the recommended 3:1 or 4:1 values.

FIG. 1

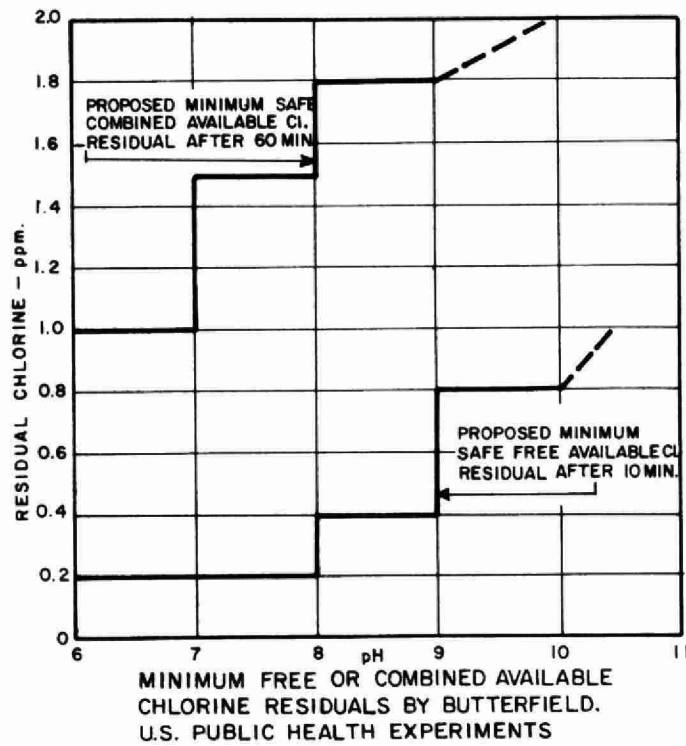
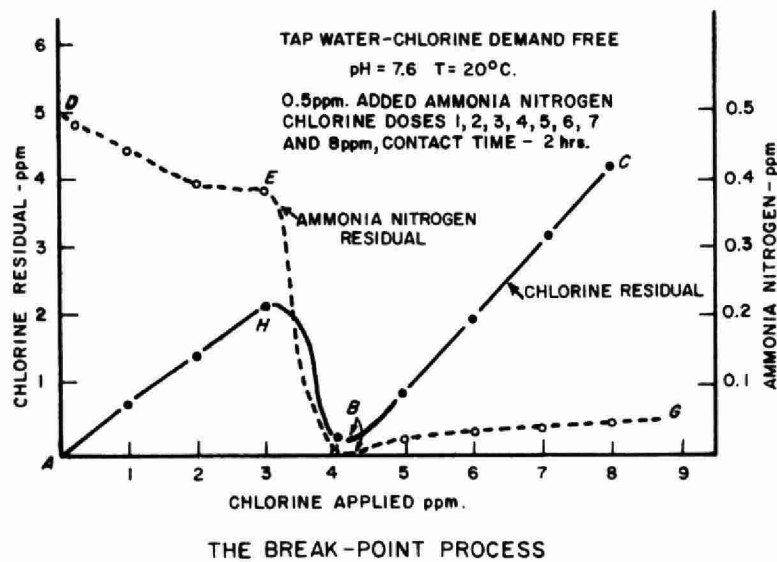


FIG. 2



Williams indicates that where unoxidized protein matter remains in the water after treatment, nitrogen trichloride may be formed in the distribution system. The conversion of the free residual leaving the plant to a combined residual is said to be effective in preventing the formation of  $\text{NCl}_3$ .

### Distribution System

One of the most important functions of a planned combined available chlorine residual is to create a stable residual which will last and thus provide protection where long retention periods are encountered. A distribution system is, therefore, ideally protected with such a stable lasting residual.

## FREE RESIDUAL CHLORINATION

### BREAK-POINT CHLORINATION

### SUPER CHLORINATION

#### General

Free residual chlorination is defined as the application of chlorine to water to product directly, or through the destruction of ammonia, a free available chlorine residual, and to maintain that residual through part or all of a water treatment plant or distribution system. The theoretical amount of chlorine required to arrive at the break point has been variously reported to be 7.5 to 10 times the ammonia-nitrogen content in the water. In practice, due to the presence of organic matter, approximately 10 to 25 times as much chlorine as ammonia-nitrogen may be required to reach this point.

The term "break-point" is derived from the shape of the chlorine residual curve produced by plotting graphically chlorine residuals obtained from increasing doses of chlorine added to a series of samples of water containing ammonia. Such a graphical plotting is given in Fig. 2. The curve AHBC represents the total chlorine residuals at the end of 2 hours of constant doses of chlorine of 1 to 8 p.p.m., added to replicate samples having no reducing agents other than 0.5 p.p.m. added ammonia-nitrogen. Point H is known as the "hump" of the chlorine residual curve and point B the break-point.

Free residual chlorination is in essence the break-point process which in turn is a refinement of and should be regarded as a phase of superchlorination.

Superchlorination is a term commonly used for the application of a heavy dose of chlorine to increase the rate of reactions. This practise results in excessive amounts of free residual chlorine and dechlorination is required before the water can be used.



Super chlorination is adapted to situations where close "breakpoint" chlorination cannot be employed due to the rapidly changing ammonia-nitrogen concentrations of the raw water, as can be the case in polluted water sources. It is noted that nitrogen trichloride problems have been encountered due to the rapid oxidation of free ammonia by dosages of chlorine well past the break point. This points out the need for close laboratory control.

Dechlorination can be accomplished by applying reducing agents such as sulphur dioxide, granular or activated carbon and by employing submerged or spray aeration to volatilize a part of the residual chlorine.

#### Application

#### Disinfection

As indicated previously the disinfection power of hypochlorous acid and hypochlorite ion, or a free available chlorine residuals is much greater than the combined available chlorine residual. At lower pH's under 7.5 the hypochlorous acid predominates. This form of residual has a high oxidation potential, and therefore, below pH 7.5, the disinfection power is greater than at higher values.

#### Taste and Odour Control

Free residual chlorination can be used to completely oxidize chlorophenolic compounds and thus eliminate the very obnoxious chlorophenolic type tastes (medicinal or iodiform taste). Free available chlorine residuals are also said to be capable of oxidizing other taste causing materials. Heavy residual along with long retention periods may be required to effect complete taste reduction and thus may limit the use of free available chlorine in some cases. One large municipality in Ontario regularly uses 8 to 10 p.p.m. of chlorine, at times up to 20 p.p.m., to obtain a 2.0 p.p.m. free available chlorine residual. Another municipality uses an average 2.3 p.p.m. of chlorine at one plant to obtain their objective of a 1.7 p.p.m. free available chlorine residual, while at another plant they may use up to 3.2 p.p.m. of chlorine to obtain the same objective.

Unless very careful break-point chlorination is being practised, only possible on a constant quality or very gradual changing quality water, dechlorination will be necessary.

## Distribution System

At times free available chlorine residuals are used to protect the distribution system but, because of the active nature of this residual it is less likely to persist for any length of time. If the water was free from protein like material, or other types of reducing agents such as iron from cast iron pipe, a free residual would be stable.

Williams has indicated that where protein like material remains in a free chlorine residual water, further reaction may create nitrogen trichlorine tastes.

## CHLORINE DIOXIDE

### General

Chlorine and sodium chlorite are mixed in a reaction tower to form chlorine dioxide. One pound of chlorine is needed to completely react with 2.55 pounds of chemically, pure sodium chlorite or 3.27 pounds of Technical Sodium Chlorite. (average analysis 78%  $\text{NaClO}_2$ ).

While the theoretical reaction ratio is approximately 1 pound of chlorine: 3 pounds of Technical Chlorite, in practise it is advisable to feed not less than 1 pound of chlorine : 2 pounds of chlorite; generally a 1:1 ratio is recommended.

Experimental studies indicate that free available chlorine residuals produced either from the application of chlorine dioxide or chlorine are equally effective in destroying bacteria. It is also found that chlorine dioxide exhibits greater chemical activity and reacts with various organic compounds and provides a more rapid oxidation of these substances than does chlorine alone.

### Application

Various writers claim that chlorine dioxide can be used to maintain chlorine residuals in distribution systems and others indicate that it can be used to remove algae, chemical, and other tastes; but its main use appears to be the elimination of chlorophenolic tastes.

Generally, when using the chlorine dioxide process, the cheaper chlorine is used at the pre position to effect disinfection, with the chlorine dioxide being used at the post position to remove the chlorophenolic tastes.

As indicated previously, the ratio of chlorine to sodium chlorite generally used is 1:1. The ratio produces an excess of chlorine in the feed flow. The actual chlorine dioxide feed required for taste destruction is usually set by experience.

PREPARATION OF CHARTS AND GRAPHS  
FOR WATER WORKS USE

by

L. M. Tobias

Administrative Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

# PREPARATION OF CHARTS AND GRAPHS FOR WATER WORKS USE

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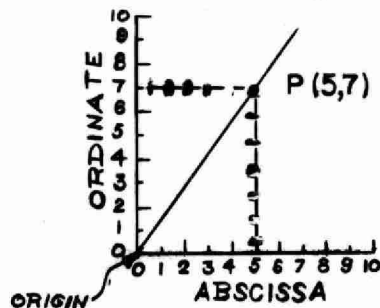
Charts and graphs play an important dual role in the operation of the water treatment plant. The first is a saving in time and effort due to minor repetitious calculations. The second and more important is that they offer rapid and accurate answers such as settings on chemical feed machines for correct feed rates, values of discharges at various pressure or heads from a pump curve and in fact the interpolation for any values in a continuously variable function.

A chart is an orderly setting down or tabulation of sets of similar values or results.

A graph is simply the pictorial representation of the chart or tabulated data.

Before going into the construction of graphs for practical purposes, it is necessary to know and understand the basic terminology used in conjunction with graphs and how to read values from them.

(See Figure 1)



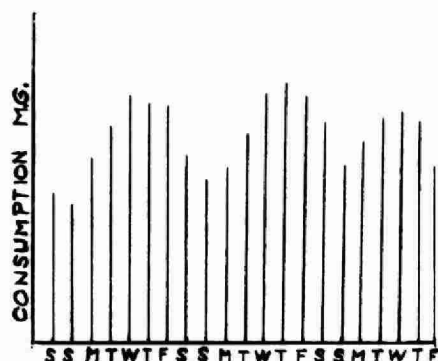
The horizontal and vertical lines are the axes of the graph and are called abscissa and ordinate axis respectively. Arbitrary values are assigned to each axis such as gallons per minute, pounds per square inch, parts per million etc. and the axis is divided into increments.

The distance used between increments is very important since the smaller the distance used between them, the less is the degree of accuracy to which the graph can be read. Values can be determined from the graph by constructing lines parallel to the axes and reading the values where these lines intersect the axes. If you follow the dotted lines from the point P in figure 1, the coordinates or values of the point P are read as the abscissa and ordinate and are equal to five and seven respectively.

In addition to the line graph just explained there are a number of other types of graphs but let us consider one other, the bar graph. Unlike the line graph which represents pictorially the changes in a continuously varying function the bar graph

represents specific individual values of the same event, which occur in succession and which are not governed by any mathematical law.

For example we can plot a graph of the quantity of water used by a town against each calendar day in the form of a bar



graph as shown in Figure 2. Each vertical line represents the total flow for one day and in itself is a complete value of one specific event. It is important to remember that at the very moment at which a new day starts, the flow is zero and increases to a maximum at the end of the day. Therefore by joining up all the points by a line graph would mean that the flow varies smoothly from one daily flow to another which of course is not true.

Since it would be impossible to present all the many ways in which a graph could be used, only a few methods will be illustrated.

The first of these is the calibration and construction of the calibration curve for a gravimetric dry chemical feeder. This example shows the construction and use of a graph involving two variables which are the rate setting device reading and the actual rate of discharge from the feeder. The equipment required for the calibration is a scale, a container to collect from the discharge and of the feeder and a timing device. The method of calibration is as follows:

If the scale on the rate setting device reads from 0 to 50 pounds per hour, select five scale readings say 10, 20, 30, 40 and 50 pounds per hour respectively. Collect a sample from the discharge of the feeder over a measured period of time for each scale setting. The period of time should be varied so that a large enough sample is obtained this minimizing possible errors. Weigh each sample and convert the respective weights and times into pounds per hour. The results should be tabulated in a chart as shown in Figure 3.

<u>Rate Setting (lbs./hr.)</u>	<u>Time (Mins.)</u>	<u>Weight (lbs.)</u>	<u>Actual Rate (lbs./hr.)</u>
10	6	1.10	11
20	5	1.83	22
30	3	1.65	33
40	2	1.46	44
50	1	0.91	55

Figure 3

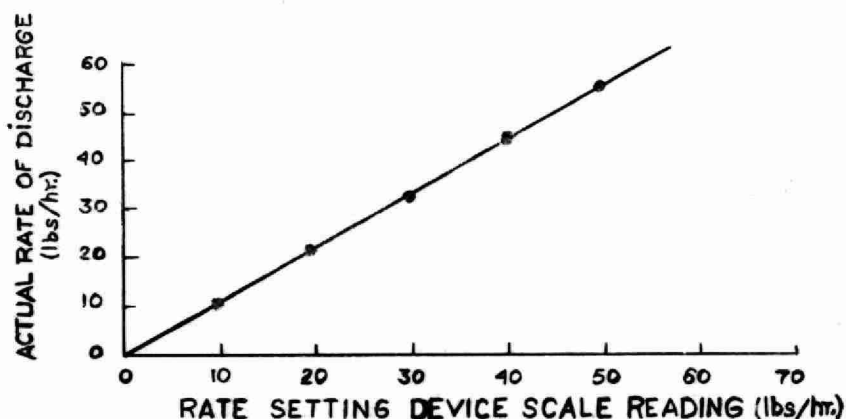


Figure 4

The actual discharge rates with the scale readings are then plotted as shown in Figure 4. It is now a simple matter to determine at which reading the rate setting device should be set to give the required rate of discharge.

The next example will show the use of a graph involving three variables. Consider the case of a solution feeder which uses the flow of water through it to power the pump. The three variables are the flow of water, the control knob setting and the amount of solution pumped. The equipment required for calibration is a graduated cylinder for collecting and measuring the volume of solution discharged, a flow measuring device and a timing device. Allow the feeder to run for a few minutes before starting the sampling. Set the control knob at  $\frac{1}{4}$  open, read the rate of flow of water and collect a sample during a measured period of time. Remember to record the various readings in a chart as shown in Figure 5. Vary the flow rate through the complete range of the instrument then repeat the same procedure for  $\frac{1}{2}$  open,  $\frac{3}{4}$  open and full open.

ONE QUARTER OPEN		ONE HALF OPEN		THREE QUARTERS OPEN		FULL OPEN	
Solution (ml/min.)	Water (gpm)	Solution (ml/min.)	Water (gpm)	Solution (ml/min.)	Water (gpm)	Solution (ml/min.)	Water (gpm)
0.5	2	1.2	2	1.7	2	1.9	2
1.9	4	2.4	4	3.7	4	3.9	4
3	8	5.5	8	7.6	8	8.5	8
4.5	12	8.2	12	11.5	12	12.8	12
3.9	16	11.9	16	15.9	16	17.6	16
4.0	20	15.2	20	21.0	20	23.5	20

Figure 5

Now plot the information in the chart on a graph (Figure 6.) The procedure is the same as for the previous example except that a curve is constructed for each control knob setting.

The graph is constructed this way because each curve represents one constant value and two variables while the whole graph represents the three variables. Therefore only two of the variables need to be known to determine the value of the third. This is shown by the dotted line on the graph.

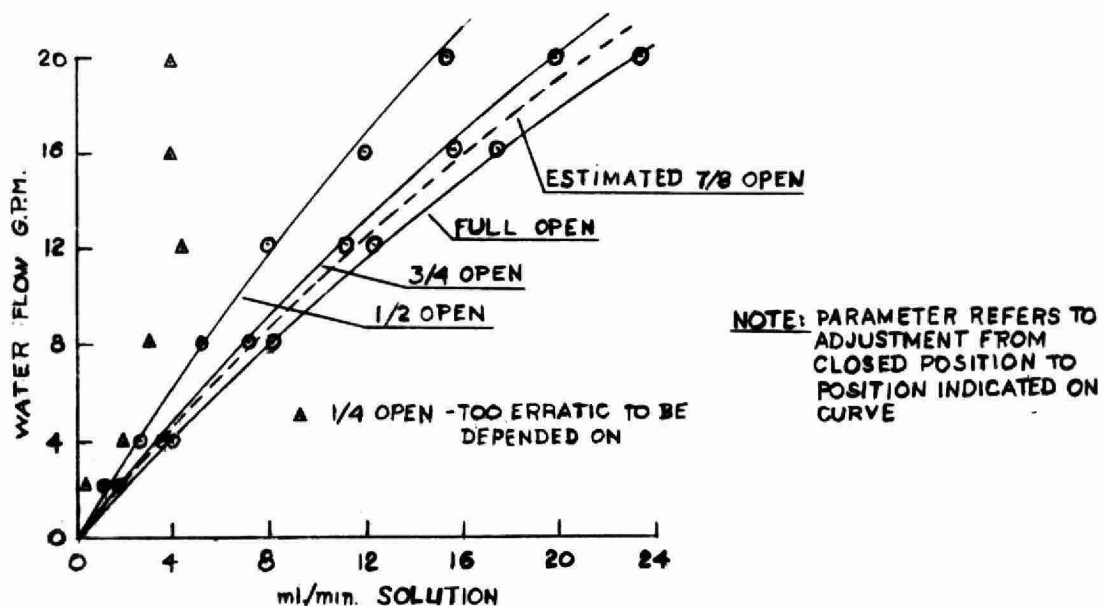


FIGURE 6



It may be necessary to operate the machine at some intermediate setting e.g. 7/8 open and the curve corresponding to this setting can be estimated by merely dividing the distance between the  $\frac{3}{4}$  open curve and the full open curve in half. This is shown as the dotted curve labelled "estimated 7/8 open".

Both of the previous examples show the use of graphs for the purpose of accuracy. The next example will show how a graph can save time and effort due to repetitious calculation. For this example a chlorine gas feeder will be used and a graph will be made to determine the chlorine dosage in parts per million (ppm) from the pounds per day of chlorine feed and the daily rate of water flow. The equation or calculation used to construct the graph is:

$$\frac{\text{chlorine feed (lb/day)} \times 1,000,000}{\text{water flow rate (gal/day)} \times 10 \text{ (lb/gal)}} = \frac{\text{chlorine dosage (ppm)}}{1}$$

or

$$\frac{\text{Cl feed (lb/day)}}{10 \times \text{water flow (MGD)}} = \frac{\text{Cl dosage ppm}}{1} \quad \text{-----(1)}$$

#### Sample Calculation

Chlorine feed = 12 lbs/day  
Water flow = 2 MGD.

$$\text{Chlorine dosage} = \frac{12}{2 \times 10} = 0.6 \text{ ppm}$$

The procedure for the construction of this graph is similar to that used for the second example ie. for every flow rate used, a series of chlorine feed rates and concentrations are calculated, giving the graph shown in Figure 7. It is useful to note that Figures 6 and 7 are similar except that the individual lines in Figure 7 are straight lines. This fact can be used to advantage since a closer look at equation (1) shows that all of the individual lines or parameters for each water flow rate, pass through the origin (or intersection of the axes). This means that only one calculation is required for each water flow rate assumed, in order to establish its curve. This eliminates the need for a tabulation of calculated values as previously required. The interpolation of a parameter line for a flow rate not calculated is obtained in a similar manner as previously indicated for example two.

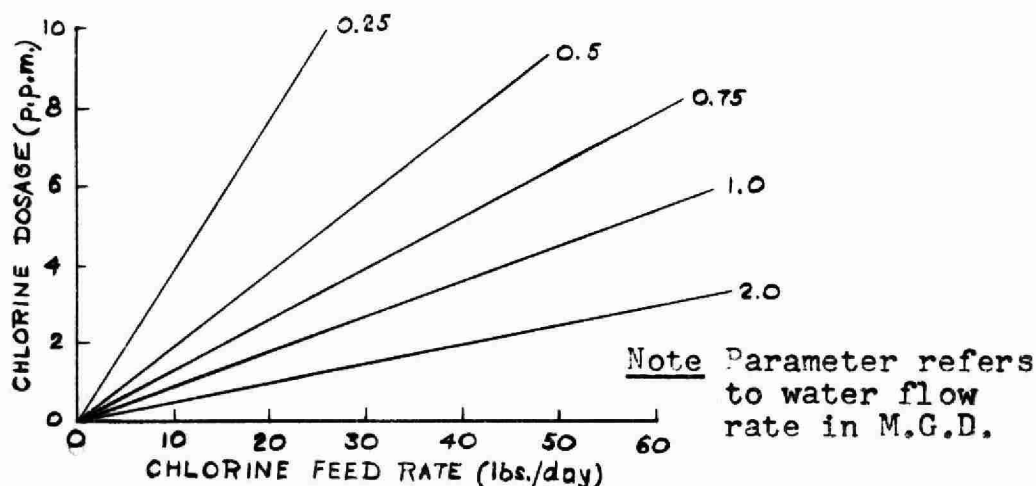


Figure 7

Another phase of water works operation which can be usefully studied in graph form is the fluctuation of water demand throughout the day and also the variation of total daily flow.

In the case of daily fluctuation of flow the graph is prepared by plotting the demand at various times throughout the day. Where the water works has the circular flow charts or strip charts it is easy to read off the demand values throughout the day. Where such charts are not available it is necessary to take flow meter readings every hour or two hours.

A typical graph of hourly demand throughout the day would look like figure 8.

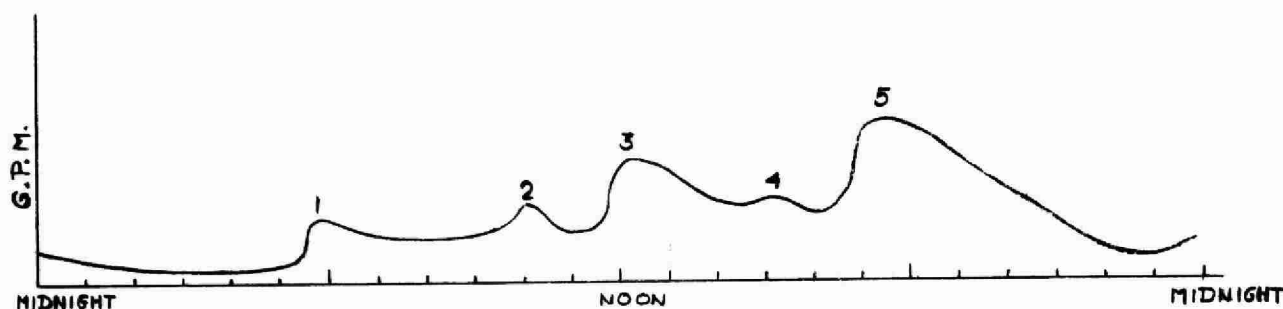


Figure 8

Note that the fluctuations numbered show demand increases caused by:

- |                   |                      |
|-------------------|----------------------|
| (1) breakfast     | (4) afternoon recess |
| (2) school recess | (5) supper           |
| (3) lunch         |                      |

If a graph like this is made for each day of the week,

it will be noted that considerable differences occur which can be explained, for example by "Washday Monday", low week industrial use, fire, water main or hydrant flushing, lawn watering etc. By establishing an average pattern for your plant you will immediately be able to recognize unusual occurrences in the system, like breaks.

Preparing a graph which shows the total daily flow for each day is valuable in providing pictorial records of change and on a long term basis will give a good indication of the trend of water consumption. The typical graph in Figure 9 is condensed and shows the total flows for each month over a two year period.

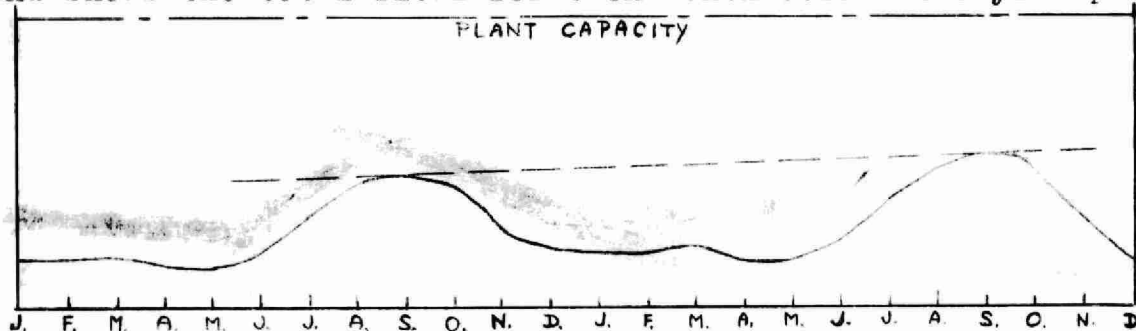


Figure 9

It is well to remember that a two year plot will not be sufficiently accurate to predict a proper trend, however an indication will be given by comparison of the general increase in consumption at equivalent times of the year. A more valid prediction could be made with say five or six annual peaks when it would be possible to take the "best line" of fit of these points. At best we could only estimate when consumption would equal production, however it is valuable to keep a close watch on the overall change to avoid a sudden realization the plant cannot produce the volume required.

Finally it is interesting to take a look at the economics of the treatment where cost figures are available. A graph can be plotted showing the total operating cost for each month and from this information it is possible to prepare a graph showing how the cost per 1000 gallons of water varies with the consumption. Such a graph might look like Figure 10.

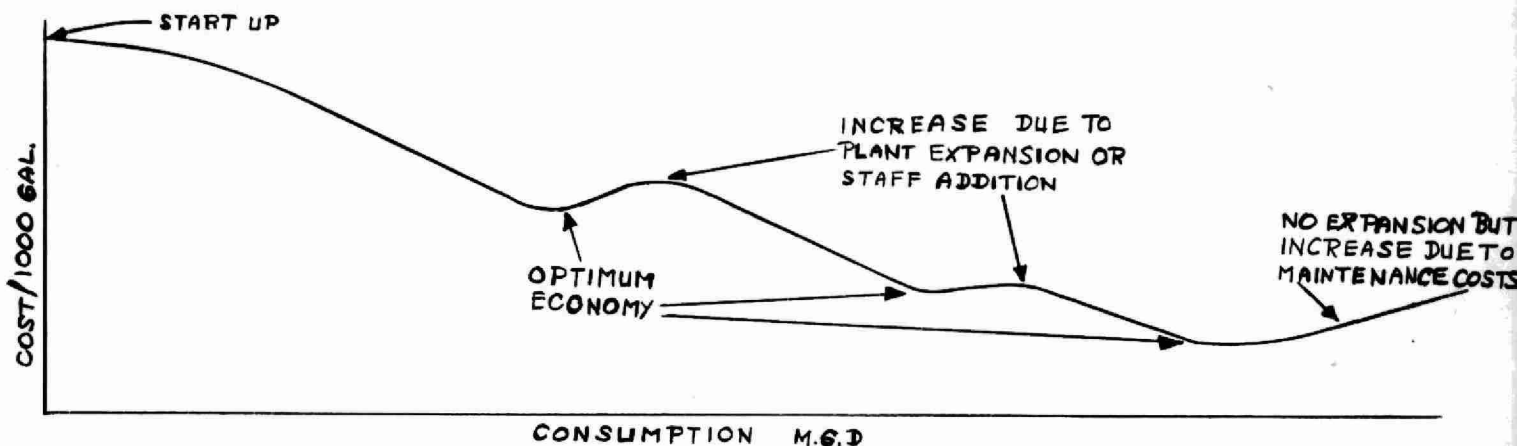


Figure 10

It is suggested that the cost per 1000 gallons will decrease with increasing consumption to point of plant capacity. A necessary expansion in equipment and or staff will tend to increase the unit cost which will again reduce to the new plant capacity. Obviously there will be a final optimum economy which cannot be bettered.

It is impossible to illustrate all the ways in which graphs may be constructed and used but with a fair knowledge of the basic principles many more problems will be recognized which can be solved or at least more clearly understood by the use of graphs.

# FLUORIDATION

by

A. B. Redekopp

Assistant District Engineer - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

## FLUORIDATION

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### INTRODUCTION

It is not the intention to discuss the pros and cons of the addition because there is an abundance of literature available that deals with these aspects of the practice of fluoridation or to discuss the legal side of this chemical treatment. It is, however, the intention of this paper to look at the subject of fluoridation from the point of view of the operator who is charged with the responsibility of operating the equipment properly to provide the required fluoride dosage and to take the necessary precautions to safeguard his own health from the toxic effects of the fluoride compounds during the execution of his duties at the water works.

A discussion of operational problems, calibration, accuracy, and maintenance of chemical feeders has been given in a separate paper by Mr. Charles Kretch.

### DEFINITION

Fluoridation is the adjustment of the fluoride content of a public water supply to approximately 1.0 ppm.

Most surface supplies have little or no fluoride content. Deep wells in Ontario range from as little as 0.1 ppm to a high of 2.2 ppm. Many well supplies therefore do not require fluoridation whereas many need the addition of only a small amount of the chemical.

### BASIC INFORMATION ON FLUORIDE CHEMICALS

	Sodium Silicofluoride	Sodium Fluoride	Hydro- fluosilicic
Chemical formula	$\text{Na}_2\text{SiF}_6$	$\text{NaF}$	$\text{H}_2\text{SiF}_6$
Weight	72 lbs/cu ft	65 lbs/cu ft	10.5 lbs/gal
Purity of Comm. Chem.	98%	98%	22-30%
Fluoride in Comm. "	60.0%	44.4%	-23.7
Solubility- 32°F	0.03 lbs/gal		
- 72°F	0.06 lbs/gal	0.35 lbs/gal	
-140°F	0.12 lbs/gal	most temp.	
pH	3.5 for 1% Sol <sup>n</sup>	7.6 for 4% Sol <sup>n</sup>	

	Sodium Silicofluoride	Sodium Fluoride
To produce 1 ppm chemical required per Million Imp. gals.	16.6 lbs.	23.3 lbs.
To produce 1 ppm chemical required per Million U.S. gals.	13.8 lbs.	19.4 lbs.

#### Which Fluoride Compound Should be Used

At present three preferred compounds are used in fluoridation: sodium silicofluoride, sodium fluoride and hydrofluosilicic acid. Other compounds are not being seriously considered now, either because of their cost, corrosiveness, low solubility, hazards of handling, or unavailability in commercial quantities.

Based on fluoride ion content, sodium silicofluoride is the least expensive source. Sodium fluoride is about two and one half times as costly, while 30% hydrofluosilicic acid is about three times as expensive.

For economic reasons the larger cities should obviously not consider the more expensive forms. For the small plant, however, several factors such as

1. equipment cost
2. desirability of using proportioning pumps for pressure feeding
3. distance from source of supply, and
4. space available for equipment affect the choice of compounds.

In Ontario out of the 12 municipalities applying fluorides artificially, 10 use sodium silicofluoride.

#### Solubility

By way of illustration, if a gallon of hydrofluosilicic acid is required to fluoridate a quantity of water, then 17 gallons of a saturated solution of sodium fluoride or 65 gallons of a saturated solution of sodium silicofluoride will be required for the same amount of water.

Practical considerations of limited time and less than ideal conditions suggest that about one-fourth of the ultimate solubility of the solid compounds can be obtained in a continuous



dissolver. This would place the solubility of sodium fluoride at 1% and of sodium silicofluoride at 0.2%. These solubility factors will, of course, determine the size of the dissolvers used with dry feed equipment. An example of this follows:

A solution of 1% strength can be obtained with approximately 10 gallons of water per lb. of sodium fluoride. Assuming a rate of feed of 12 lbs. per hour the water requirement will be 120 g.p.h. or 2 g.p.m. A 5 min. retention period will therefore require a 10 gallon dissolver. Laboratory tests and field experience have indicated that a 5 min. dissolving time is adequate at the above concentrations.

From the table it will also be noted that the solubility of sodium silicofluoride varies considerably with temperature. In order to ensure that all of the sodium silicofluoride is dissolved at low temperatures it may be necessary to provide heating facilities for the solution water at some installations.

### Corrosiveness

The most corrosive chemical is the hydrofluosilicic acid. It is generally shipped in rubber lined drums from which it is drawn directly, and discharged to the point of application through plastic and plastic-lined pipes.

Of the two solid compounds it will be noted that a 1% solution of sodium silicofluoride has a low p.H. of 3.5. This necessitates the use of rubber hose or plastic pipe to convey this solution. Sodium silicofluoride solutions have been found to destroy steel pipes very rapidly. Sodium fluoride solutions are much less corrosive and many plants have been using steel pipes for sodium fluoride solutions with satisfactory results.

### CHEMICAL STORAGE

The storage of chemicals should be convenient to the feeder for any size plant. The chemical should be stored in a reasonably dry room not directly on a concrete floor. Bags and even drums should be placed on boards or grids to allow circulation of air to prevent "sweating" on the bottom.

Hydrofluosilicic acid must be stored either in unopened glass carboys or in rubber-lined shipping containers to prevent the release of gases or vapours.

### TYPES OF INSTALLATIONS

The best installation may be defined as one that has the best combination of the following factors:

1. Simple mechanical feeding device either liquid or dry.
2. Simple piping or injection arrangement.
3. Minimum chemical handling.
4. Minimum maintenance and operational duties.
5. Means for maintaining a reliable permanent record.

The various types of systems of installations available are listed below. The five conditions mentioned above must be considered in evaluating the suitability of these systems for any particular plant.

1. Rubber or plastic diaphragm type proportioning pump, delivering hydrofluosilicic acid by gravity directly from the acid container on scales to point of application.

This type of installation requires minimum chemical handling. Diaphragm proportioning pumps are preferable to piston or plunger type or centrifugal pumps because of their lower maintenance requirements and greater simplicity. A single unit proportioning pump will treat up to 40 M.G.D. with 1 ppm of fluoride.

2. The same installation as above delivering against pressure.

If calcium and magnesium are present in excessive amounts they may deposit on and clog the nozzle, thereby further complicating high-pressure injection. Pressure feeding always involves additional equipment and more extensive maintenance than is required by gravity feed.

3. Diaphragm type proportional pump for sodium fluoride using a saturator and feeding by gravity or under pressure.

Saturators have many advantages that favour their use in plants in which they are applicable. The constant solubility of sodium fluoride assures a uniform concentration, over a wide range of temperatures. Water for the solution is automatically added to the tank by means of a float valve. As the water trickles through the bed of crystalline grade, 20-40 mesh, sodium fluoride, a solution of 4% constant strength is produced. A sand bed on the bottom of the saturator provides a positive barrier between the crystalline sodium fluoride and the solution outlet. The saturator may be placed at a low level to facilitate filling and may hold a comparatively large amount of chemical. An entire 100 lb. bag may be added at one filling.

If hard water is encountered (hardness exceeding approximately 75 ppm) the saturator make-up water must be softened, thereby complicating the installation and increasing maintenance.

A saturator with a proportioning pump of a 7.5 gph capacity that used 4% solution will treat 3 mgd with 1 ppm of fluoride.

4. Dry Feeder (volumetric on platform scale or gravimetric weighing dry feeder) with dissolver, delivering sodium fluoride or sodium silicofluoride solution by gravity to point of application.

Dry feeders are ordinarily used in most medium and large-sized plants or wherever gravity feed can be used. In Ontario the majority of the installations are of the volumetric feed type.

Volumetric feeders will deliver as little as 3 to 4 oz. per hour to treat supplies of 200,000 M.G.D. or greater. Gravimetric (weighing) dry feeders will feed as little as 1 lb. per hour, but are generally used for rates of more than 5 lbs. per hour or to treat supplies of 5 M.G.D. or greater.

5. The same installation as above equipped with ejector or pump to deliver against pressure.

If hard water is encountered ejectors or pumps should not be used for rates which exceed approximately 12 to 20 lbs. per day of sodium fluoride. Ejectors and pumps will clog excessively with calcium or magnesium fluoride unless dissolver water is softened or a sequestering agent is used.

6. Proportioning pump for feeding 3 to 4% sodium fluoride solutions by gravity or against pressure.

This involves careful weighing of the chemical and measuring of the make-up water to be used in the solution drum to determine the strength of the fluoride solution obtained. This installation is similar to the one used for feeding hypochlorites.

Again, if hard water is encountered, a softener should be provided to make up the solution and prevent loss of fluoride which will precipitate out as magnesium or calcium fluoride.

This type of installation would be applicable to the small well supplies and pumping stations serving rural communities.

Now, having selected the equipment, where do we apply the chemical?

## POINT OF APPLICATION

The point of application of the fluoride is an important factor. Almost every water supply presents a different problem, sometimes involving a compromise between what is considered the best point of application and the best location for the chemical feeder. In general, fluorides are applied most effectively at that point, where the risk of losing them in a subsequent treatment is least.

The conventional application point for fluoride solutions is in filter effluent lines or in the clear well. At small plants, using well supplies and pumping stations, the solution should be injected into the discharge from the deep well pump.

Fluoride should not be added with or before coagulants or with softening chemicals. Feeding sodium fluoride solution ahead of lime softening has on occasion caused a loss of approximately one-fourth of the fluoride. Aluminum sulphate has even been used to effect fluoride removal.

Chlorine can be added anywhere in the plant or distribution system. There are no known reactions between fluorides at 1.0 ppm concentrations in water and compounds formed in water after chlorination. Fluorides at this concentration have no bactericidal effects. Fluoride, unlike chlorine, is not used up in the water.

## RATE OF FEED CHECKING

Good engineering requires that means be provided to check the feeder accurately for the amount of chemical being delivered.

Provisions for continuous testing are so inexpensive and simple to provide that they should not be omitted. This operation provides a means of keeping necessary records and more closely controlling plant operations.

If hydrofluosilicic acid is pumped by a proportioning pump to the application point, the original acid container can be placed on a platform scale and loss in weight read at convenient intervals.

Loss-in-weight type gravimetric feeders have built-in scales that control the feed rate. Chart records can easily be attached to gravimetric feeders. Volumetric feeders can be provided with a loss-in-weight indicating and recording scale head.

If sodium fluoride solutions are to be pumped or

measured by any other type feeder, several simple methods of continuous testing may be used. The simplest is a scale attached to the inside of the tank that can be easily read by the operator, although, for a deep tank, a float, cable, pulley and scale on the outside of the tank would be better. A sightglass will show the level in the tank at all times and, if connected to the tank and pump, will serve as a test gage to show how much the pump is delivering with each stroke.

By providing an accurate water meter on the make-up water supply to a sodium fluoride saturator, a record of the sodium fluoride used may be kept.

Dry feeders for low rates of feed should be placed on a platform scale (as described above) for acid tanks, and vernier indicators used to check the feed at low rates.

Dissolvers should not be on the scales of small feeders for two reasons:

1. When feeding a few ounces per hour, the slightly fluctuating water level in the dissolver makes loss-in-weight tests unreliable, except for long runs.
2. Condensation on the dissolver increases in humid weather and runs down upon the scale thus increasing the weight on it.

Large dissolvers used for higher feed rates would also not be placed on scales because of their great weight.

#### INCRUSTATION OF FEEDING EQUIPMENT

Incrustants form occasionally in solution tanks, feeders, and feeder lines. If excessive amounts of calcium or magnesium are present in the solution water, calcium fluoride or magnesium fluoride will settle out and become lost. Scale formation may be prevented by softening all the water used to convey the sodium fluoride solution or by treating it with a sequestering agent such as Calgon or Nalco 918. The sequestering agent required is a function of water volume as well as chemical characteristics although the relationship is unknown and can be determined only by trial and error. Experience indicates that treatment may range from 7 ppm to 15 ppm. On the other hand there is very little additional labour involved in removing the precipitated fluorides from solution tanks, inasmuch as sodium fluoride contains insoluble material which also must be removed periodically.

Generally it has been found that sodium silicofluoride



is not scale forming. Calcium and magnesium do not readily precipitate at low pH values.

Although hydrofluosilicic acid does not combine with the chemicals in the water to form a scale or precipitate it can play other tricks with the water works operator. Hydrofluosilicic acid is a liquid and is fed as a liquid. Frequently it is desirable to dilute it. Generally this can be done without difficulty, but sometimes a jell forms which clogs strainers. This can be overcome by notifying the manufacturer, who can correct the trouble by a slight change in formulation. The jell usually consists almost wholly of silica in jell form.

#### TOXICITY OF FLUORIDES

About 230 mg. of fluoride would have to be ingested to create sublethal toxic effects. Assuming that 2 liters of water are consumed by an individual each day, the toxic amount would be equivalent to 115 ppm fluoride in potable water. This is equivalent to a dose of 1150 lbs. of fluoride ion per million gallons or 2670 lbs. of 95% strength sodium fluoride per million gallons. The lethal dose of fluoride ion is about 4 grams. Thus, again assuming the consumption of 2 liters of water per capita per day, this would be equivalent to the addition of 2000 ppm fluoride or about 23.4 tons of 95% sodium fluoride per million gallons, far beyond the capacity of the chemical feeders used.

In case the operator is exposed to an excessive amount of fluoride, a physician should be called immediately, and the following antidote applied.

Give a tablespoon of salt in a glass of warm water and repeat until vomit water is clear. Precede by lime water or 1% calcium chloride solution if available. Give strong tea or coffee or teaspoonful aromatic spirits of ammonia in water.

Let's hope that none of us has to go through this. It should never be necessary if you follow the few basic safety practices given next.

#### SAFETY MEASURES

The hazards inherent in the handling of fluoride by water works personnel can be eliminated by utilizing four safeguards:

1. Choice of fluoride compound.
2. Proper handling procedures.
3. Personal protective devices.
4. Dust collecting apparatus.

The inhalation of fluoride dust is the principle hazard to operators. This can be minimized considerably by using a recently developed crystalline sodium fluoride and other granular forms which contain practically no particles small enough to form dust. Careful handling of the powdered compounds, either while emptying barrels or when transferring small quantities from the shipping containers to solution tanks, is most important.

The operator should follow all instructions provided by the manufacturer. Spilt fluorides should be removed by wet mopping. Masks should be worn to protect operators in the event dust is accidentally generated. Rubber gloves should be worn because fluorides are a skin irritant. Body surfaces exposed to fluoride dust should be washed thoroughly with water. Where large quantities of fluorides are dumped into feeder hoppers from barrels or bags, blower operated dust collectors should be installed in the hoppers. Pneumatic conveyors should be vacuum operated.

Present practice in water treatment plants is to obtain equipment permitting the fluoride feeder hopper to be filled no oftener than once a day. If reasonable care is used in handling the fluorides so as to produce the least dust, little danger to the operators is involved.

For a small plant the proper design of the hopper or loading door will permit placing the entire container within the hopper to allow the bag or drum to empty itself after the door is closed.

Actually, the greatest hazard occurs in the larger plants, where the fluorides are dumped from a barrel into a hopper opening which is at floor level. Occasionally, the fluoride arches in the barrel and then suddenly emptying, throws the cloud of dust into the air. In such installations, the dust exhaust system should be made part of the hopper equipment.

Of the available materials, hydrofluosilicic acid is by far the least hazardous. There is, of course, no dust for employees to breathe, and there is no occasion, with a properly vented installation, for employees to breathe any fumes whatsoever. In case of a break or spillage one might breathe the room atmosphere for considerable periods of time without harm. The material is not harmful on the skin if washed away within a reasonable period. Rubber gloves, goggles, and rubber aprons should be used when handling drums. In one case in Philadelphia a leak in the pressure discharge of a pump squirted the 36% material right into the eyes of a mechanic. His eyes were washed with water, and he was taken to the hospital where they were again washed, the treatment being repeated the following day. No ill effects have ever been evidenced.



## TEST FOR FLUORIDE

A reliable laboratory test most often employed is a colorimetric method that depends upon the formation of a non-ionized zirconium fluoride salt that reduces the zirconium in a zirconium alizarin lake and thereby reduces its colour. Hence this method is really a colorimetric method in reverse, in that the greatest intensity in colour occurs when no fluoride is present and rapidly fades as the fluoride content increases. This method has been found reliable for potable water containing chloride ions up to 500 ppm and sulphate ion up to 200 ppm. Alkalinity or acidity does not interfere when present in amounts up to 200 ppm expressed as calcium carbonate. If these constituents exceed these amounts, or, if iron, aluminum, phosphate, colour, or turbidity are present in quantities, a distillation method which is more complicated, must be employed. Modifications to this method are outlined in "Standard Methods for the Examination of Water, Sewage, and Industrial Waste." The interference by residual chlorine is removed by dechlorination with sodium thiosulphate or arsenite reagent.

Reagents required for making the colorimetric determination are as follows:

1. Acid zirconium alizarin reagent.

Note - Stored in a refrigerator, the reagent is stable for at least 2 months.

2. Standard sodium fluoride solution made up so that 1 ml. is equivalent to 0.01 mg. fluoride. This solution may be made by dissolving 0.221 g. NaF in distilled water and diluting to 1 liter, then diluting 100 ml. of this stock solution to 1 liter with distilled water.

### Procedure for Solution Colour Standards Test

1. In matched 100 ml. Nessler tubes make up standards by adding increasing amounts of standard NaF solution. The standards recommended are: .0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, and 1.4 mg. of fluoride. Make each of these standards up to 100 ml. with fluoride-free distilled water.
2. Place 100 ml. of the sample in another matched Nessler tube.
3. Bring both the sample and the standards to near the same temperature. Since the colour of the zirconium alizarin lake varies with the temperature, the sample and the standards should be within 2°C of the same temperature.

4. Add 5 ml. of the acid zirconium alizarin reagent accurately measured with a 5 ml. volumetric pipette to the sample and each of the standards.
5. Do not allow the sample and the standards to stand much longer than one hour as they tend to become cloudy and difficult to read.
6. Compare the sample with the standards and record the amount of fluoride as that of the standard that most nearly matches the sample in colour.
7. Multiply the amount of fluoride to be present in the 100 ml. sample by 10 to determine the quantity in ppm.

### Commercial Testing Equipment

An example of the commercial equipment is the Hellige Aqua Tester and Fluoride Colour Disc. The method of performing the test with such apparatus eliminates the tedious continual preparation of standard colour solutions described above, and the apparatus can be used by water plant operators who do not have special training. This test is similar to the test for residual chlorine determinations.

It should be pointed out, however, that this test employing the fluoride colour disc, although it is desirable because of its simplicity, does, on many occasions, provide only an approximate fluoride determination. The difficulties encountered here are the colour disc itself which is made up according to a certain pigment in the colour code, and the stability of the acid zirconium alizarin reagent which, by the way, is the same compound as used in the solution colour standards test. In the first instance it is known that the pigment in the chemical used in the preparation of the reagent may vary slightly from batch to batch. This difficulty is circumvented in the solution colour standards test by using the same reagent in the standards and in the sample. In the second case any deterioration of the reagent which occurs with time will again affect both the standards and the sample in the solution colour standards test thus cancelling out its effect, while with the commercial tester, this effect can introduce a considerable error in the results obtained. It may be stated that, in most instances, the commercial colour disc testing equipment can only serve to provide approximate information on the fluoride concentration. It is a good tool as a check to determine if one is dosing fluoride in the required range.

### Records

The best check on the fluoride dosage provided is to

compute daily the fluoride concentration in ppm from the water flow records and weight of the chemical introduced into the water supply. This daily record should be used to control the fluoride dosage. Normally, only minor adjustments on the fluoride feeder are required to maintain an average dosage of 1.0 ppm.

Complete records should be kept of the amounts of water treated and quantities of fluoride used.

#### OWRC Laboratory

To provide this Commission with a continual record of the fluoride chemical feed to communal water supplies, samples for fluoride determination should be submitted to the OWRC Laboratory bi-monthly.

#### SUMMARY AND FINAL CHECK LIST

1. Store the chemical convenient to the feeder. The chemical should be stored in a dry room and preferably not directly on the floor.
2. Make sure the feeder has an accuracy of at least plus or minus 3%.
3. Refill the hoppers of the machine before it becomes empty to prevent flooding of the chemical through the machine.
4. Use a mask and rubber gloves when handling fluoride compounds.
5. If scale forms in the dissolver or solution piping with sodium fluoride solution, it is generally advisable to eliminate it either by using soft water or by using sequestering agents such as Calgon or Nalco 918.
6. Check the feeder regularly to determine if the proper amount of chemical is being fed. Carry out the fluoride test daily, and calculate the fluoride concentration in ppm by determining the amount of water pumped and chemical added. Keep daily records of the tests and calculations performed. Maintain a fluoride concentration of 1.0 ppm in the finished water. An operating margin of 0.8 to 1.2 ppm is permissible.
7. Submit samples bi-monthly to the OWRC Laboratory for fluoride determination.

In conclusion, it may be stated that the control of fluoride application presents no more difficulties than the control of a number of other water treatment chemicals. To the trained water plant operator, the control of all types of chemical treatment is a serious responsibility. Thus, the control of fluoridation should not be taken lightly, but actually presents no greater difficulties to the operator than he is faced with continually.

# COAGULATION

by

J. G. Duncan

Supervisor - Purification Branch - OWRC

An Address To  
The Ontario Water Resources Commission  
Intermediate Water Works Course  
Toronto, Ontario  
November 27, 1961

## COAGULATION

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Supervisor, Purification Branch - OWRC

In the lecture given to the first Water Works Operators' course the chemistry and laboratory side of coagulation has been covered. In this paper it is intended to discuss some of the problems that are met when coagulation is studied in our water-works. These problems arise for various reasons. In some cases, the plant has become overloaded, and in other cases the process of coagulation has been misunderstood and plants have been built in which efficient coagulation is difficult to attain, or a combination of these reasons may exist.

Let us mention first one type of plant in which we feel it is impossible to produce satisfactory coagulation. Many of you have visited some of our older plants in which alum is fed to the water from an alum pot and then passes immediately to pressure filters. In this instance, alum has very little opportunity of doing the job it is intended to do, and, in fact, it often passes right through the filter and coagulates after reaching the distribution system. The best that can be hoped for from a set-up of this type is to apply a layer of alum floc on the surface of a freshly washed filter and then turn the alum pot off.

When sent out to investigate coagulation problems, we always take along our jar testing equipment and the first step is always jar tests to determine if proper dosage of alum is being used or whether it is going to be necessary to use some other coagulant or coagulant aid to obtain the required results. As in some cases, alum alone will not form a floc. From the results of the jar tests the chemical dosage will be adjusted, and if this does not produce the desired results, the efficiency of the plant will be investigated. In some cases, the chemical feeder is found to be at fault and the coagulant is not completely dissolved, and some of it falls to the bottom of the pumpwell or settling basin and is not used.

The point where most of our plants have trouble is in the mixing. If you will recall in my first lecture, I emphasized that in order to obtain good efficiency from a coagulant it was necessary to have a rapid mix to disperse the chemical completely through the body of water followed by a slow mix that would allow the chemical to coagulate the turbidity or colour and build up the floc to a size that would settle rapidly. The time of the rapid mix varies from half a minute to five minutes depending on the type of mixing equipment used. Thirty minutes is considered by many to be adequate for coagulation, though a longer time than this is recommended for real cold waters.

In many of our older plants there are no mixing chambers. The alum is fed into the pumpwell and the turbulence of the water passing through pump and pipe leading to the settling basin is all the mixing that is provided. It is quite obvious that this short mixing period is not adequate for efficient coagulation. In some cases there is also a large pumpwell and the alum is not picked up before the coagulation has started; in this case, the pump will disperse the floc that has formed and this results in even lower efficiency.

It should not be too costly to make a marked improvement in a system of this sort. The first thing would be to instal a rapid mixer, or, if this is impossible, to make sure the coagulant was fed directly to the intake of the pump. The second change would be to instal baffles at the entry end of the settling basin and set up hydraulic mixing such as spiral flow or over and under baffles. In some cases, it would not be too difficult to build a baffle across the settling basin and introduce mechanical mixing. This will reduce the settling time, but any time used for mixing will more than make up for the settling time lost by an improvement in the overall efficiency.

Then we had another type of plant, in which the pump is again used for rapid mixing. This is followed by hydraulic mixing such as over and under baffles or spiral flow tanks. Since the plant was built, the water consumption has increased greatly, and the velocities in the mixing tanks is now much too high. In some cases, the baffles have deteriorated and there is considerable short-circuiting; in other cases, it has been necessary to by-pass some of the baffles to reduce the loss of head in the mixing tank. In a case like this, it is necessary to change some of the baffles so that the velocity of the water is reduced to a point where flocculation can take place, and, if possible, the size of the mixing tank is increased to allow for more flocculation time. In most cases, the best answer would be to remove the baffles and instal mechanical mixing that would give better control over mixing at all flow rates.

We might mention here that hydraulic-type mixing has very limited flexibility and is only efficient over a very limited range of flows. At low flows the floc tends to settle out and at high flow good floc formation is prevented.

At this point we might consider some of the difficulties that are encountered in settling basin. In some cases, the water is carried from the mixing chambers to the settling basins through pipes that are too small, and this results in high velocities and turbulence that destroy much of the effectiveness of good mixing. In other cases, the water is pumped from the settling basin to the filters and the floc that has not settled is dispersed by the pump and makes



efficient filtration difficult. Situations like this are usually costly and difficult to change. Sometimes, when a settling basin is examined it is quite obvious by the movement of the floc that there is turbulence and high velocities present. In such cases there is a lack of baffles or the baffles being used are not doing the job they were installed to do. Usually, with a bit of study and changing of baffles, a situation like this can be corrected and improved settling obtained, but do not be disappointed if the first change made does not correct the situation.

A few of the problems that have been encountered in coagulation have been mentioned, and it is felt that if some simple change in equipment or plant construction can be made to improve these conditions this is the first thing to do, but if after these changes are made it is still not possible to get satisfactory coagulation, then it may be necessary to make use of things such as coagulant aid to complete the job.

We know, for instance, that activated silica will shorten the time necessary for coagulation and flocculation and produce a floc that is tougher and more difficult to disperse, and its use will no doubt extend the useful life of many of our older plants. The use of activated silica, however, does present some problems. If it is produced by the batch system, it requires considerable room for the installation of activating and holding tanks. The preparation of activated silica has to be carried out carefully or one may end up with a tankful of gel that is useless for water treatment. If filters are equipped with fine sand, it may be necessary to install surface washers and increase flow rate for back washing. In other words, activated silica could be the answer to many of our coagulation problems, but it might be difficult to use and also costly.

From what we have seen in the past, we feel sure that the efficiency of coagulation could be improved in many of our plants. One of the objects of this course is that waterworks operators should be informed of proven methods to achieve this desirable result.

ONTARIO WATER RESOURCES COMMISSION

INTERMEDIATE WATER WORKS COURSE

December 1, 1961

Name \_\_\_\_\_ Municipality \_\_\_\_\_

1. (a) What adverse conditions are caused by iron in water?  
(b) How much of this element (iron) is permitted before trouble is expected?
2. (a) A drilled well has reduced in capacity from 150 gals. per min. to 30 gals. per minute. What can be done to stimulate the well to return it to close to its original capacity?  
(b) A screen in a drilled well is of stainless steel. Indicate the best material for the bottom 20 ft. of the casing?  
  
Bronze\_\_\_\_ Brass\_\_\_\_ Stainless steel\_\_\_\_ Galvanized materials\_\_\_\_.
3. (a) Should activated silica be added with the alum or separately in the flocculation of water?  
  
Added with\_\_\_\_ Separately\_\_\_\_  
(b) In adding alum at a plant is it better to have a fast mix followed by a slow mix; a slow steady mix; or a slow mix followed by a fast mix in a pump?  
  
Fast mixing followed by slow mixing\_\_\_\_  
A slow steady mix\_\_\_\_  
A slow mix followed by a fast mix in a pump\_\_\_\_
4. (a) What is the purpose of the loss of head gauges on a filter?  
(b) Why should valves or a filter be opened slowly?  
(c) If the filters have been running for an average of 48 hrs. between washings, and all at once the runs drop to 12 hrs. but insofar as you can see there is not much change in turbidity of the applied water, what would you suspect?

5. What approximate percent removal of bacteria can be expected in a filter plant by the following treatments?

Flocculation \_\_\_\_\_  
Sedimentation \_\_\_\_\_  
Rapid sand filtration \_\_\_\_\_

6. (a) Why is most cast iron pipe that is now installed lined with cement mortar or bituminous enamel?  
(b) Name some of the advantages and disadvantages of asbestos cement pipe.  
(c) What are the advantages of prestressed concrete pipe for the sixteen inch mains and larger?
7. (a) In common practice pipe is designed for four classes of working pressure. What are these pressures?  
(b) What should be done when pipe, special valves and other appertinances to a water works distribution system are delivered to the site of the work.
8. Indicate a preventive maintenance program for chemical feeders at a water works plant.
9. (a) What safety precautions should an operator take in handling fluoride compounds?  
(b) What dosage should be maintained in a fluoridation program at a water works plant?

1.0 p.p.m. \_\_\_\_\_; 2.0 p.p.m. \_\_\_\_\_; 5.0 p.p.m. \_\_\_\_\_

10. (a) What is the prime purpose of adding chlorine to water?  
(b) Describe one of the following methods of applying chlorine to water:

marginal chlorination, break-point chlorination, super chlorination or chlorine dioxide.